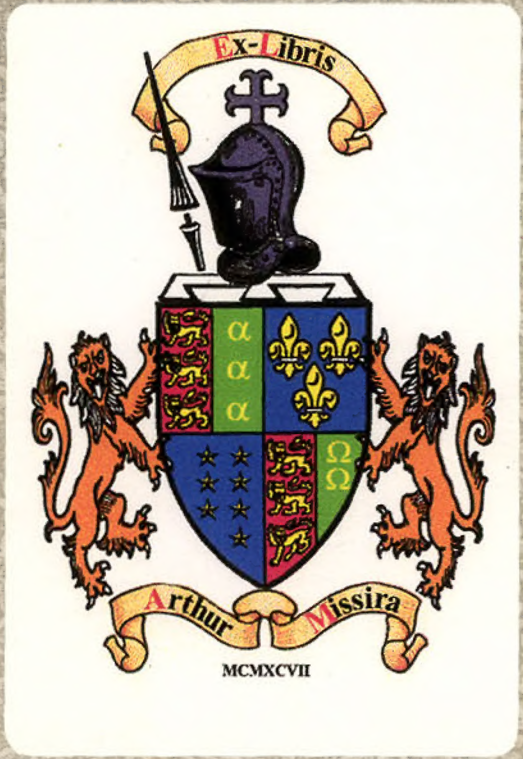
ASTRONOMICAL LESSONS - GORE.

# ASTRONOMICAL LESSONS

J. E. GORE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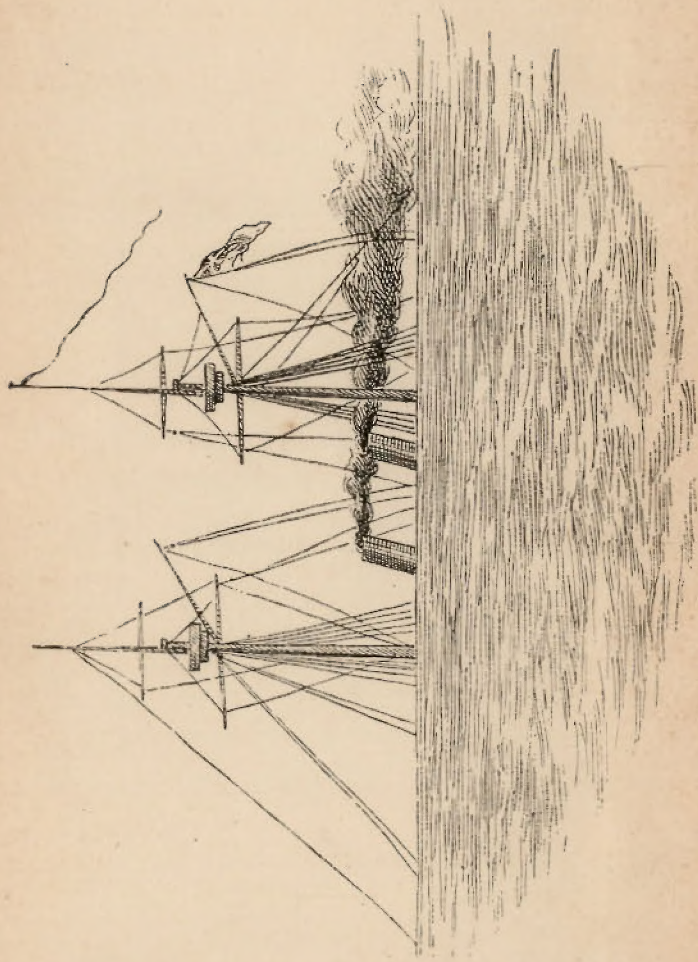

FIG. 1.—MAN-OF-WAR "HULL DOWN" AS SEEN WITH A TELESCOPE. [*Frontispiece.*

# ASTRONOMICAL LESSONS;

OR,

*CHAPTERS ON THE ELEMENTARY PRINCIPLES AND FACTS OF ASTRONOMY*

FOR THE USE OF STUDENTS AND YOUNG PEOPLE.

BY

JOHN ELLARD GORE,

F.R.A.S., M.R.I.A., F.R.G.S.I., ASSOC.M.I.C.E.,

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AUTHOR OF

"The Scenery of the Heavens," "Planetary and Stellar Studies," "Southern Stellar Objects," &c.

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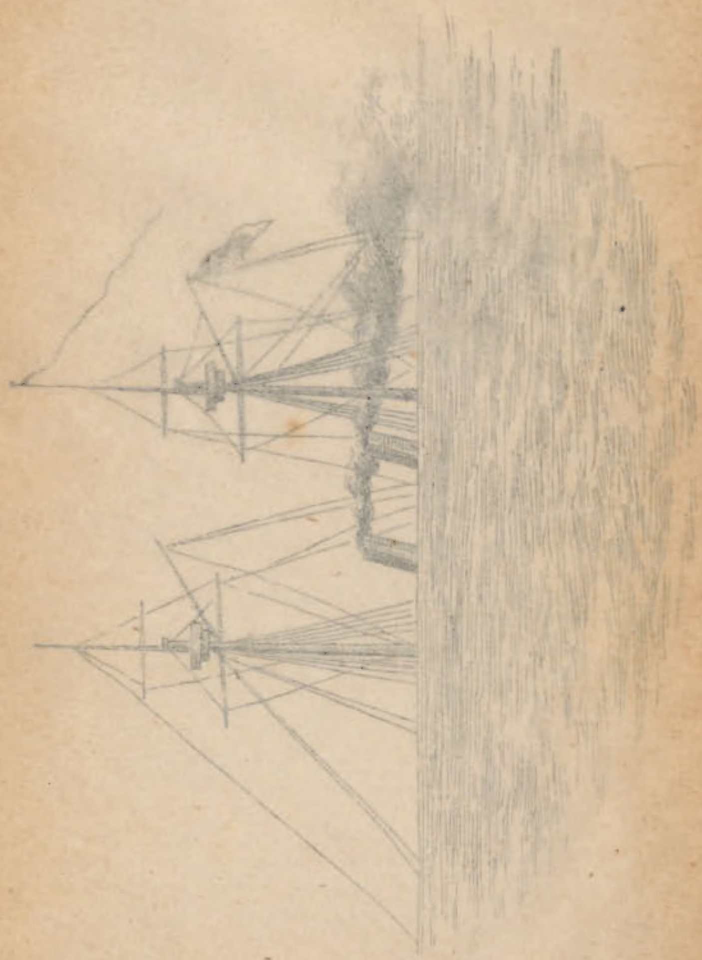

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"The works of the Lord are great, sought out of all them that have pleasure therein."—PSA. cxi. 2.

"Snatch me to heaven; thy rolling wonders there,
World beyond world, in infinite extent,
Profusely scatter'd o'er the blue expanse
Show me; their motions, periods, and their laws
Give me to scan."

THOMSON (*Autumn*).

# PREFACE.

THE following chapters on the elementary principles and facts of Astronomy are intended as an introduction to larger and more advanced works on the subject, and will, it is hoped, be found useful to young people and beginners in the study of this fascinating science

*October*, 1890. J. E. G.

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# CHAPTER I.

## THE FIGURE OF THE EARTH.

THE word Astronomy means the science which treats of the heavenly bodies, their motions, and the laws which govern them. It is derived from two Greek words, *αστηρ* (*aster*) a star, and *νομος* (*nomos*) a law—the law of the stars. It is a most interesting study, and has attracted the attention of mankind since the earliest ages of antiquity. We will commence our study with the figure and dimensions of the earth on which we live. The shape of the earth is nearly that of a globe or sphere.

The reader may ask: How can it be proved that the earth is a globe, and not a plane surface, as ordinary observation would lead us to suppose?

There are several convincing proofs of the globular shape of the earth. For instance, if the earth were a flat plane, when the sun rose above the horizon of any place it would at once illuminate the whole terrestrial surface. This, we know, is not the fact, for the sun rises in London several hours before it rises in New York. How the supporters of the

"flat earth" theory explain this admitted fact I do not know. It certainly could not be explained on any common-sense principle. But perhaps the most familiar, and certainly the most convincing proof is the appearance of ships at sea. If you stand on the shore on a calm day, and watch a vessel sailing away from your eye, would you not expect to see the masts disappear before the hull, if the surface of the sea were a level plane? The hull, being so much larger than a comparatively thin mast, should remain for a longer time visible.

You will see, however, that the very reverse of this takes place. The hull of the ship is the *first* portion to disappear, and then the masts gradually sink out of sight, till at last nothing but the extreme top of the highest mast remains visible. This clearly shows that the surface of the sea is globular, and hides the ship's hull from our view. You will see also that the bounding-line of the horizon, called the *offing* by sailors, is a sharp, clearly defined line, not fading away in haze and distance, as would be the case were the surface of the water a level plane.

This is the appearance as seen with the naked eye, but—it may be asked—if we examined the ship with a telescope, would not the hull then become visible? No; the appearance would be exactly the same. The frontispiece represents the telescopic view of a "man of war"[1] when it is "hull down," as the sailors term it. Were the earth flat, as some

[1] The *Warspite*.



mistaken people imagine, it is quite impossible that any such appearance could ever be seen. The ship would continue visible as a *whole*, and would become apparently smaller and smaller, until at last it became invisible even in a powerful telescope. This seems quite evident, but there are other proofs of the earth's rotundity.

The shadow of the earth on the moon during a lunar eclipse is another proof. An eclipse of the

FIG. 2.—IMAGE OF THE SETTING SUN REFLECTED FROM A CALM SEA.

moon is caused by the earth passing between the sun and the moon, and in a partial eclipse we see that the shadow on the moon's face is bounded by a circular line. Now nothing but a spherical body could, in *all* positions, throw a circular shadow. A very interesting proof of the globular form of the earth has recently been given by Prof. Ricco, the well-known astronomer of the Palermo Observatory. He finds that the image of the sun, reflected from the surface

of a calm sea, is of a well-marked oval shape, and he expresses his surprise that the ancient astronomers did not notice this phenomenon, and infer from it that the earth is really globular. M. Ricco made his observations with a telescope of 4½ inches aperture, from a height of 236 feet above the sea level, and about 1¼ miles from the shore. He finds that when the sun's lower limb is touching the sea horizon, the vertical diameter of the reflected image is reduced about ten minutes of arc, or nearly one-third of the sun's apparent diameter (see fig. 2). This result agrees with theory, and *proves* that the earth is a sphere.

The earth is, however, not a perfect sphere. It is slightly flattened at the north and south poles—somewhat similar to an orange (but not to so great an extent); the diameter at the equator being about 26½ miles longer than that through the poles.

If you look at an artificial globe you will see that it is mounted on an axis, on which it turns. This represents the earth's axis, and the extremities of this axis are termed the poles. The earth of course has no real axis, like the artificial globe, but as it turns round once in the 24 hours, astronomers call the imaginary line round which it rotates the *axis*, and the extremities of this line are the earth's *poles*. This imaginary axis points very nearly to a tolerably bright star, known to astronomers as the Pole Star.

The equator is an imaginary circle round the earth,



every point on which is at an equal distance from the poles. The most accurate measurements make the diameter at the equator 7925½ miles, and at the poles 7899 miles, the difference being, as I have said, about 26½ miles. The mean or average diameter is therefore 7912¼ miles.

## CHAPTER II.

### THE DIURNAL MOTION OF THE EARTH.

I SPOKE of the rotation of the earth on its axis in 24 hours. This is the cause of day and night. But—it may be asked—if the earth really rotated on its axis should not the motion be, in some way, visible to observation ? So it is ; in the apparent motion of the sun, moon, and stars. In what other way the motion *could* become sensible I cannot conceive. It must be remembered that the motion is very steady and uniform, that the earth's atmosphere is carried round with it, and that we have no external objects, except the heavenly bodies, to which we can refer the motion. When on board ship, out of sight of land, with a cloudy sky, and neither sun, moon, or stars visible, it is impossible to tell (without watching the "wake" of the ship in the water) whether she is moving in a straight line, or going round in a circle. But if you were near land, and looking out of the cabin window, you could at once detect the motion of the vessel by watching objects on the shore, which would seem to move in the opposite direction. In



the same way when travelling in a fast railway train, you see outside objects apparently flying the other way. We must therefore conclude that either the earth turns on its axis, or the whole star sphere rotates round the earth every 24 hours ; which is the more probable ? there can be no third alternative. It certainly seems more probable that a comparatively small body, like the earth, should turn round on its axis than that the gigantic sphere of stars should rotate. The reader may ask, however : Is there any *direct proof* of the earth's rotation ?

Yes ; an experiment devised by M. Foucault proves conclusively that the earth *does* rotate on its axis in 24 hours. If a heavy weight be suspended by a long wire, and caused to vibrate like a pendulum in a certain direction, say north and south, it will be found, if attentively watched, that the plane of vibration rotates. At the equator there would be no effect, but at the north and south poles the plane of vibration would make one rotation in 24 hours ; or in 6 hours from the commencement of the experiment, the pendulum would be vibrating from east to west, instead of from north to south. We cannot, of course make the experiments at the poles, but experiments made at Paris agree with the mathematical theory of the motion, and prove, beyond all doubt, that the earth *does* rotate on its axis.

Here is another proof : As the top of a high tower is further from the earth's centre than the base of the tower, if the earth rotates the top will move faster

than the base. Hence if a ball be dropped from the top, we should expect it to fall a little to the east of the vertical line. Careful experiments have shown that such is the case. There are some other proofs,[1] but the two I have just given are quite sufficient to establish the truth of the theory to any reasoning mind.

In speaking of the horizon it should be mentioned that there is a *sensible* and a *rational* horizon. The

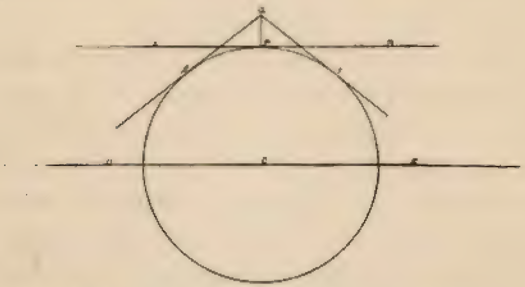


FIG. 3.—SENSIBLE AND RATIONAL HORIZON.

*sensible* horizon is the circle bounding the view of a spectator from any point on the earth's surface. The *rational* horizon is that supposed to be seen from the centre of the earth. In the accompanying figure APB is the *sensible* horizon of the point P, and DCE is the *rational* horizon of the same point. From a high point we should, however, see a greater

[1] We know that Mars, Jupiter, and Saturn rotate on their axes (and probably all the other planets). It seems, therefore, from analogy, highly improbable that the earth should be the only planet having no axial rotation.



distance. From the elevation Q (see fig. 3) the distance of the *sensible* horizon would be QS or QT, and the higher the point of observation, the greater the distance visible. The *rational* horizon is, of course, an imaginary one, so that all the motions of the heavenly bodies must be referred to the *sensible* horizon.

The setting sun remains visible for a longer time as seen from the top of a mountain than from the plain below. Some years since an aeronaut ascended in a balloon from Dublin, and was carried across the Irish Channel. When approaching the coast of Wales the balloon descended, a little after sunset, nearly to the surface of the sea. The aeronaut then threw out nearly all his ballast, and the balloon suddenly rising to a great height the sun again became visible, producing the curious phenomenon of a sunrise in the west!

The difference between the *sensible* and the *rational* horizons will not, however, make any difference in the extent of the heavens visible to a spectator on the surface of the earth. For, as the earth is a mere point in comparison with the nearest of the stars, there will be no perceptible difference whatever between the heavens as seen from the surface and the imaginary view visible from the centre of the earth.

Thus we always see the *whole* hemisphere; and about half the number of stars in the heavens are visible at one time. If you imagine the small point representing the centre of the circle in fig. 3 to represent the

earth you will see that a whole hemisphere is visible from every point on the earth's surface. From a high mountain, or from a balloon, slightly *more* than a hemisphere would be visible. It is true that when clouded the sky looks somewhat like a flattened arch, but this is clearly due to the fact that the clouds overhead are really nearer to the eye than those near the horizon (the height of the clouds at both points being the same). In a cloudless sky, however, the hemispherical shape is very evident and unmistakable.

## CHAPTER III.

### THE FIXED STARS AND THE SUN'S APPARENT MOTION.

CATALOGUES of the stars have been made by astronomers, even of thousands not visible to the naked eye. But, the reader may ask, is this possible? the number visible even to the naked eye seems quite innumerable.

This is, however, a popular fallacy—due chiefly to an optical illusion. But in reality the number of stars distinctly visible to the naked eye is comparatively *small.* The number given in the catalogues of the ancient astronomers is *very* small. That of Hipparchus contains only 1,022, and that of Hevelius—the last of the astronomers who observed the places of stars without a telescope — only 1,533, observed at Dantzig.

The number really visible to good eyesight is, however, somewhat larger. Those visible without optical aid have been carefully mapped by two eminent astronomers, Behrmann and Heis, both of whom possessed exceptionally keen eyesight. For the stars visible in northern latitudes Heis found a total of

5,356, and Behrmann for the southern portion (not observed by Heis) 2,306, making a total for the whole heavens in both hemispheres of 7,662. Of course only one-half this number (one hemisphere) can be seen at any one time, or an average of about 3,830.

As many of the stars observed by Heis and Behrmann are very faint, even this small number would not be visible to every one. If we confine the enumeration to stars of the 6th magnitude—about the average limit of most eyes—the total, in both hemispheres, is about 4,000, giving an average of only 2,000 as visible at any one time to ordinary eyesight.

From these figures it will be seen that the lucid stars (as those visible to the naked eye are called) are very thinly scattered over the surface of the heavens. Were there on an average even one star to each space of the area of the full moon there would be no less than 180,000 stars visible to the unassisted eyesight, or 90,000 at one time. This will give an idea of how very sparsely scattered the lucid stars really are. This fact may appear very surprising. Some may think that millions are visible on a clear night. The idea, indeed, seems a very common one, but it is none the less erroneous. The student may depend upon it that astronomers do not make serious mistakes of this kind. The numerical results I have given are such that it would be in vain to attempt to disprove them. Any one who tries to do so merely shows his



ignorance and inability to understand scientific facts and reasoning.

The number of stars is, however, largely increased when the heavens are examined with a telescope. Even with a good opera-glass the number is considerably increased, and the more powerful the telescope the larger the number visible. Not, however, in proportion to the size of the telescope. The number of telescopic stars appears to be limited also. Assuming that an infinite number of stars were scattered through infinite space, it may be *proved* mathematically that the whole heavens would shine with the brightness of the sun! (and with a corresponding amount of heat!) But even on a clear night the sky is more remarkable for its blackness than for its light. This is another surprising result, but it cannot be disputed.

To give an idea of the way in which the stars apparently "thin out" as we examine the fainter ones, I may mention that an estimate has been made of the total number of stars visible with the giant telescope of the Lick Observatory, California—recently constructed — and two of the greatest American astronomers, Professors Newcomb and Young, give as the probable number 100 millions. Now on the theory of uniform distribution through infinite space, I find the number which *should* be visible in this great telescope is over 3,000 millions, or 30 times the number which it actually shows!

How is this very limited number of stars to be explained? Some astronomers have suggested that

the luminiferous ether of space may—for stars at a vast distance—absorb the light of the fainter stars altogether. But if we are to consider the ether as a *perfect* fluid, as scientific men maintain, this explanation will not hold good. The most probable explanation seems to be that the sun and Solar System belong to a cluster of limited dimensions, in fact that the *visible* universe is really limited. If other external universes exist—as is probably the case, space being infinite—they are possibly invisible to us owing to immensity of distance.

The student will notice that the stars are of very different degrees of brightness. St. Paul says, "One star differeth from another star in glory." Those visible to the naked eye have been divided—even by the ancient astronomers—into six magnitudes, the brightest being called first magnitude, those clearly fainter second magnitude, and so on to the faintest visible to ordinary eyesight, which are called sixth magnitude. Telescopes, however, continue this series of magnitudes further, and with the largest telescopes the faintest stars are considered to be of the 16th and even 17th magnitude.

It will also be noticed that among the brightest stars some are perceptibly brighter than others. The earlier astronomers included all the brightest stars in the first magnitude, but Sirius, for instance, is far brighter than any of the others; modern observations show it to be nearly 2 magnitudes brighter than an average star of the first magnitude. The bright stars



Arcturus, Capella, Vega, and Procyon in the northern hemisphere, and Canopus, $\alpha$ Centauri, and Rigel in the southern are also distinctly above the average.

The following stars may be considered as average stars of each magnitude:—Of the 1st magnitude, Aldebaran, Altair, and Spica; of the 2nd magnitude, $\alpha$ Persei, $\alpha$ Andromedæ, and the Pole Star in the northern hemisphere, and $\beta$ Argûs, $\lambda$ Scorpii, and $\gamma$ Crucis in the southern hemisphere. Of the 3rd magnitude, $\beta$ and $\delta$ Draconis, $\zeta$ Tauri, $\epsilon$ Virginis, $\beta$ Cygni, $\theta$ Aquilæ, and $\gamma$ Gruis. Of course between each magnitude there are a number of stars of intermediate brightness, the heavens containing stars of all grades of brilliancy, from Sirius to the faintest star visible in the Lick telescope.

The names just mentioned refer to the imaginary constellation figures into which the ancients grouped the stars for convenience of reference. These groups have been retained, with few alterations, by modern astronomers. The Greek letters were added by Bayer in 1603.

Before attempting to identify these constellations in the sky, we must know how to find the four points of the compass, North, South, East, and West. The student will know that at noon the Sun is due South, and that looking at it then, the North is behind him, the East on his left hand, and the West on his right hand.

But at night—it may be asked—when we have not the sun to guide us, how are we to find the north?

The student will probably have heard of the Pole Star. He may also know the seven bright stars forming the Plough, or Charles' Wain. Here is a drawing of it (fig. 4). It is in the constellation of *Ursa Major*, or the Great Bear. Well, a line drawn from $\beta$ to $\alpha$, and produced, will nearly pass through the Pole Star. Not *exactly*, but near enough for the purpose of identifying the Pole Star, which, as I have said, is a standard star of the second magnitude, and therefore a fairly conspicuous one. For this reason these two stars are called the "pointers."

The Pole Star is not *exactly* at the Pole, but so near it that to *ordinary* observation it does not perceptibly alter its position. This star will be always useful in finding the north, and from it, and the stars of the Plough, the positions of other stars may easily be determined. For instance, if the curve formed by the three stars in the tail of the Bear ($\epsilon$, $\zeta$, $\eta$ in the diagram) is continued on, it will pass near a very bright star. This is Arcturus, one of the brightest stars visible in Europe. Again, if we draw an imaginary line from $\gamma$ to $\beta$ and produce it, it will pass near another very bright star. This is Capella, or $\alpha$ Aurigæ, the principal star of the constellation Auriga, the Charioteer. Again, if we draw a line from $\delta$ to $\beta$ and produce it, it will pass near two tolerably bright stars. These are Castor and Pollux in Gemini or the Twins, the northern of the two being Castor, and the lower, and somewhat the brighter of the two, Pollux. Another line from $\delta$ to $\gamma$ will pass

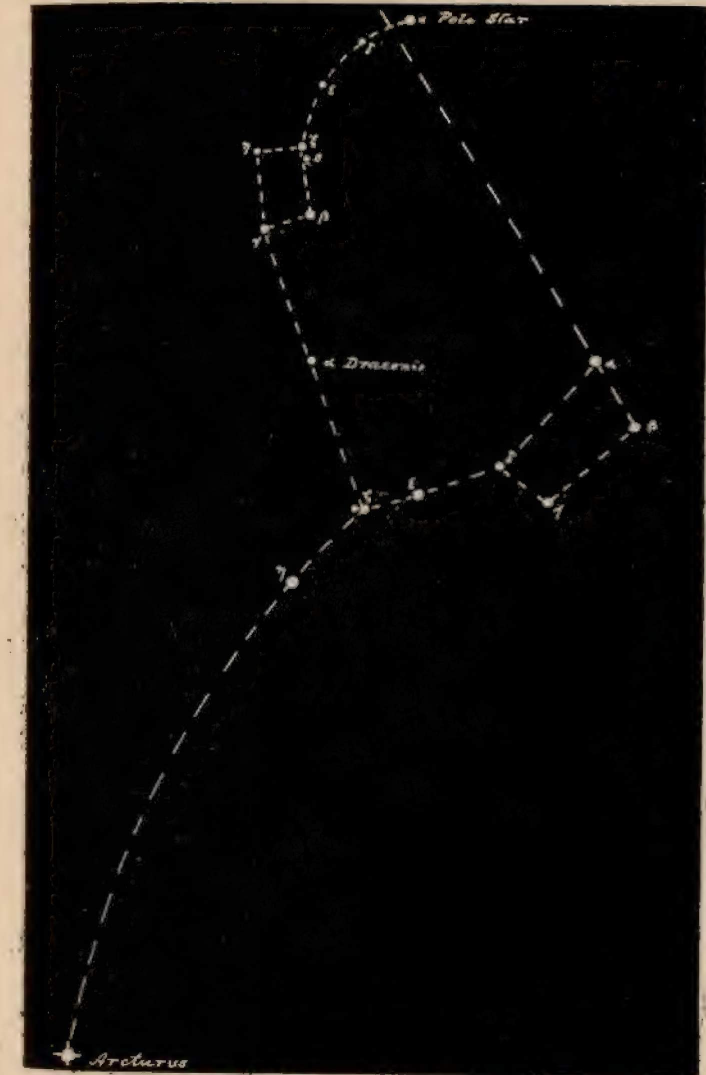



FIG. 4.—THE PLOUGH AND THE POLE STAR.

near a bright star called Regulus, or $\alpha$ Leonis, sometimes called *Cor Leonis*, or the Lion's Heart. This star is in the handle of the so-called "Sickle," the figure formed by $\alpha$, $\eta$, $\gamma$, $\zeta$, $\mu$, and $\epsilon$ in Leo, which very much resembles a reaping hook.

On the opposite side of the Pole Star from the Plough you will see five conspicuous stars, forming a W-shaped figure. This is Cassiopeia's Chair. In this way, and with the help of a celestial globe or star atlas, you will soon learn to know all the brightest stars at a glance, and from these brighter stars the fainter ones can be found when required. The star Regulus is remarkable for another reason : it lies close to the ecliptic.

The ecliptic is an imaginary circle in the sky which the sun apparently moves along during the course of the year. The term ecliptic is derived from the fact that eclipses of the sun and moon occur in or near this circle.

The sun, however, seems to have a motion across the heavens every day. This, called the *diurnal* motion, is simply due to the rotation of the earth on its axis once in 24 hours. This apparent motion, which is familiar to every one—even to those ignorant of astronomy—is quite distinct from the *annual* motion, which can only be detected by careful observation.

In what way can we detect this annual motion of the sun? If we take any well-known star near the ecliptic, and visible towards the west after sunset,



and if we observe this star every evening for some weeks, we shall soon notice that it sets earlier each evening, and at last approaches so near the sun that it is lost in his rays, and can no longer be seen. After some weeks this same star will become visible in the morning sky before sunrise, showing that it has apparently passed behind the sun. It then rises earlier and earlier each morning until it rises at sunset, when it is said to be in "opposition" (or opposite to) the sun, and is then visible all through the night for several months, until at last it again rises and sets with the sun.

This apparent motion of the sun among the fixed stars is due to the *real* motion of the earth round the sun, and when once recognized seems quite as obvious as the diurnal motion.

The student may ask, Do *all* the stars disappear and reappear in this way? Well, most of them do, at least in northern and southern latitudes. Those, however, within a certain distance of the Pole—equal to its altitude (or height above the horizon of the place)—never rise or set, as they do not pass below the horizon at any time. These are called *circumpolar* stars, and are visible at all seasons of the year, and at all times of the night.

The altitude of the Pole Star—or rather the altitude of the Pole—is its angular elevation above the horizon, and is equal to the latitude of the place of observation. The proof of this is very simple, and from the student's knowledge of Euclid he will

easily understand it. Let APEBD (fig. 5) represent the earth, C its centre, and AB its axis, pointing towards the pole in the direction AS. Let DCE, at right angles to AB, represent the earth's equator. Let P be the place of observation, and FPG the *sensible* horizon of the place—at right angles to PC. Then, since the Pole Star is at an immense distance from the earth, the line PT pointing to the Pole is parallel to CAS. Hence the angle TPF is equal to the angle PFC. But since the angles FPC and ACE are right angles, we have PFC and FCP together equal FCP and PCE. Take away the common angle FCP, and PFC is equal to PCE. But PCE is the latitude of the place P, being the angular distance from the equator E. Therefore PFC, or TPF, is the latitude of the place P. This relation is very useful for finding the latitude at sea by measurement of the sun's altitude at noon.

Before explaining the method of finding the latitude I must first explain that there is another imaginary circle in the heavens called the celestial *equator*. This is the circle in which the plane of the earth's equator, if produced, would intersect the star sphere. Hence, at the poles of the earth this circle will coincide with the horizon, and at the equator it will pass through the zenith, or point exactly overhead. The plane of the ecliptic is inclined to the plane of the equator at an angle of 23½ degrees, this being the angle between the earth's polar axis and a perpendicular to the plane of its orbit, or the plane

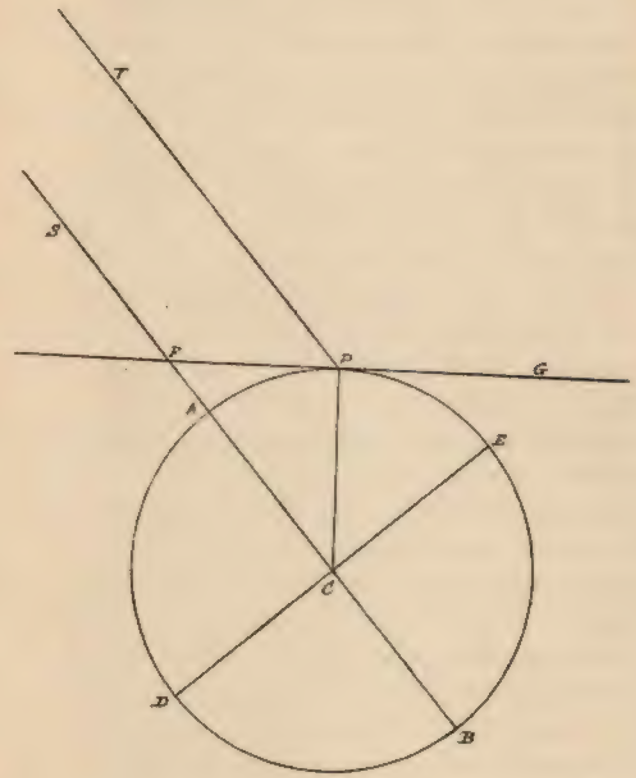



FIG. 5.

of the ecliptic.[1] See fig. 6, in which NESQ represents the earth, N the North Pole, S the South Pole, EQ the earth's equator, AB the plane of the ecliptic. It will be seen that the plane of the ecliptic is at one point raised $23\frac{1}{2}$ degrees above the equator, and at the opposite point is $23\frac{1}{2}$ degrees below it. Now the sun in its apparent motion round the heavens and moving along the ecliptic will at one point be situated $23\frac{1}{2}°$ north of the celestial equator. This occurs on the 21st of June, the "longest" day. Six months afterwards, or on the 21st of December, the "shortest" day, it will be $23\frac{1}{2}°$ south of the equator, and at two other points it will be exactly *on* the equator. These points, where the plane of the ecliptic intersects the plane of the equator, are called the *equinoctial* points, because day and night are then of equal length. The sun arrives at these points on March 21st, the *Vernal Equinox*, and on Sept. 21st, the *Autumnal Equinox*. At all other periods of the year it is either above or below the equator, and its distance north or south of this line—technically called its Declination—is given for each day of the year in a book called the *Nautical Almanack*, which is published some years in advance for the use of vessels making long voyages.

We know that every day at noon the sun is due south, and at its highest point above the horizon—or on the meridian of the place, as astronomers term it.

[1] The inclination of the polar axis to the plane of the ecliptic is of course $90°-23\frac{1}{2}°=66\frac{1}{2}°$.

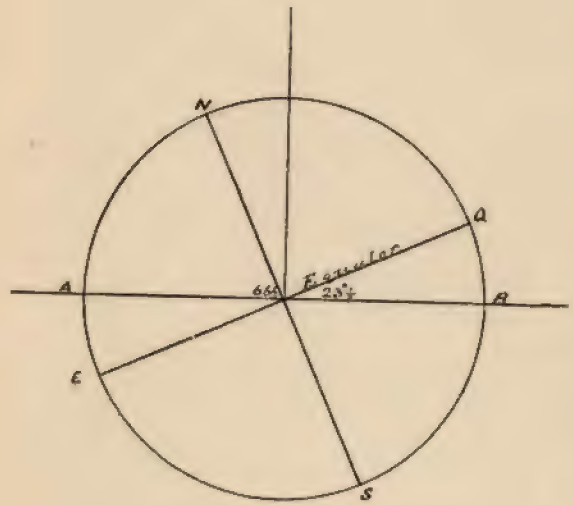


FIG. 6.

Now, to find his latitude at sea the captain of a ship measures the altitude of the sun at noon with an instrument called a sextant, and then knowing from the Nautical Almanack the sun's declination on that particular day, he can find the altitude of the celestial equator, and thence the latitude of the place of observation. There are some small corrections to be made to the observations, but I will explain the general principles of the method. If the sun is at the time north of the equator the captain deducts the declination from the observed altitude, and if south of the equator he adds it. He then subtracts the altitude from 90 degrees, and the difference is the latitude of the place. Let us try an example. The altitude of the sun at noon on the 21st of June is observed from a ship to be 60°; what is the latitude? On the 21st of June the sun's declination is 23½° north of the equator. This must be deducted from 60°, which gives 36½° for the altitude of the equator, and 36½° deducted from 90° gives 53½°, the required latitude.

If the same altitude 60° was observed on the 21st of December, what would then be the latitude? In this case 23½° must be *added* to 60°, which gives 83½°, and this deducted from 90° leaves 6½° for the latitude.

Now, supposing the observed altitude on the shortest day was found to be 70° instead of 60°, let us find the latitude. 70° added to 23½° gives 93½°. But how can this be deducted from 90°, as it is a greater number? Well, the difference would be



in algebra *minus* 3½ degrees, or 3½ degrees less than zero. This shows that the celestial equator is 3½ degrees to the north of the zenith, from which we conclude that the place of observation is *south* of the terrestrial equator, or in 3½ degrees *south* latitude.

The latitude could also be found by observing at night the meridian altitude of a star whose position is known with reference to the celestial equator; but at sea it is usually found more convenient to observe the sun.

I have explained how the latitude of a place is found. How can the longitude be determined? This is a more difficult problem than the other. There are several methods of finding the longitude, but the one generally used at sea is the method by "lunar distances." In the Nautical Almanack the angular distance of the moon's centre from certain bright stars and planets is given for every three hours. If, then, the distance of the moon from a bright star or planet is measured with the sextant at any time, the Greenwich mean time of the observation can be calculated, and from the local time at the place the longitude may be found, reckoning 15 degrees of longitude to each hour of time. The local time may be found from sextant observations of the sun's altitude.

## CHAPTER IV.

### THE ANNUAL MOTION OF THE EARTH AND THE SEASONS.

IN addition to the diurnal motion of the earth on its axis the earth has another motion—an annual motion round the sun. This motion causes the different seasons of the year.

But before I explain how the seasons are due to the earth's annual motion, perhaps the student would like to hear some proof that such a motion actually takes place. For it may seem to him that the sun's apparent motion among the stars might be explained equally well by a real motion of the sun round the earth. And he would be quite correct in that idea; the observed motion could be equally well explained on either supposition. But the evidence in favour of the earth's motion is so great that it seems impossible to resist it. As I explained, in speaking of the earth's rotation on its axis, we could not expect to be in any way conscious of its motion through space in its journey round the sun. The motion is so smooth and uniform that we could have no possible means of



ascertaining that such a motion exists, except by watching some *external* object, and such an apparent motion we see in the sun. We have now to determine whether it is the sun or the earth which performs a revolution in the course of a year. One or other of these motions *must* take place; there is no other alternative.[1] The best proofs of the earth's motion round the sun are mathematical ones, and for this reason, probably, the theory of the earth's motion is disputed by paradoxers, who are unable to understand the mathematical reasoning on which it is based. One proof is as follows:—The sun's distance from the earth can easily be ascertained by astronomical observations. This distance has been very approximately determined, and admits of no reasonable doubt. Knowing this distance and the sun's apparent diameter, its actual size follows by a very simple calculation. In this way it has been found that the sun is a vastly larger body than the earth. Now Sir Isaac Newton has proved that when two bodies revolve round each other, according to the law of gravitation, they must both revolve round a point between them, which is called "the common centre of gravity." In the case of the sun and earth the centre of gravity—owing to the vast size of the sun—is situated near the centre of the sun, and hence,

[1] The idea that the sun revolves round the earth once in 24 hours, as maintained by the supporters of the "flat earth" theory, is altogether preposterous and unworthy of serious consideration.

according to this principle, the earth must revolve round that point, the sun remaining nearly stationary.

Suppose a large globe and a small one are connected by a rod, and we try to balance the combination on another rod, it will be found that the point at which both globes will balance is very much nearer to the larger globe than to the smaller one, and the greater the difference in the size of the globes the nearer will this point fall to the larger globe. This point is called the "centre of gravity" of the two globes. If the larger globe is very large in comparison with the small one it will be found that the point falls within the surface of the larger globe, as happens in the case of the sun and earth.

This seems a satisfactory proof. But it might be objected that in this reasoning we assume the truth of the law of gravitation, which some may consider as an hypothesis and not a demonstrated truth. This objection would be reasonable. The proof I have given, although a very strong one, may appear to some not quite conclusive, so astronomers have sought for still stronger evidence, and this they have found in a remarkable phenomenon known as the "aberration of light." If the earth moves round the sun it may be easily proved, from the sun's known distance, that the velocity in its orbit must be about 18½ miles per second. The velocity at which light travels has been found by several methods, and is known to be about 186,000 miles per second. Now the light coming to us from a star



combined with the earth's motion causes an apparent displacement in the position of the star, as seen from the earth. This displacement is of course very small, owing to the comparatively slow motion of the earth, and can only be detected by very accurate instruments, but there is no doubt whatever that it exists. Were the earth at rest—as some argue—no such displacement could possibly occur. We therefore conclude that the earth is in motion; and as the observed "aberration" agrees exactly with the theoretical velocity, we conclude that the earth really does revolve round the sun. The supposed motion of the sun round the earth would *utterly* fail to explain the observed phenomenon,[1] and is therefore unworthy of serious consideration.

The planets also revolve round the sun, as we know from observation, and this is another argument in favour of the earth's motion, "the argument from analogy," as it is called. Why should the earth be the only body in the Solar System which remains at rest? This is a strong argument, but the argument from the "aberration of the stars" seems to me far stronger; indeed it is altogether unanswerable, and to the astronomer and mathematician the earth's motion round the sun is a *demonstrated fact.*

The earth's path round the sun is not a perfect circle. It is nearly so, but not exactly. The real

[1] This is the case with most of the hypotheses known as "paradoxes." They completely fail to explain observed phenomena, and are therefore worthless.

form is that of an ellipse, having what mathematicians call a small eccentricity. An ellipse is an oval figure with two points on its longer axis called the *foci*, and the sum of the distances of any point from the two foci is a constant quantity, and equal to the longer axis of the ellipse.

The point where the longer and shorter axis of the ellipse cross at right angles is called the *centre* of the ellipse. The distance from the centre to either focus is called the "eccentricity" of the ellipse. The greater the distance of the focus from the centre the more elongated is the ellipse. The orbits of comets are generally of this shape. The less the distance of the focus from the centre of the figure, the more nearly the ellipse approaches a circle in form; and when the focus coincides with the centre the ellipse becomes a circle. In fact the circle is only a particular case of the ellipse, or, as a mathematician would express it, the circle is the limiting form of the ellipse when the eccentricity is reduced to zero.

If we call the mean distance or semi-axis major 1, the present eccentricity will be expressed by the decimal fraction 0·0168, or very nearly by the vulgar fraction $\frac{1}{60}$. In other words, if we divide the semi-axis major into 60 equal parts, the distance of each focus from the centre will be equal to 1 of these parts. If therefore we assume that the earth's mean distance from the sun is 92,890,000 miles,[1] we find that the distance of the sun (which is placed in one of the

[1] Corresponding to a "solar parallax" of 8.80″.

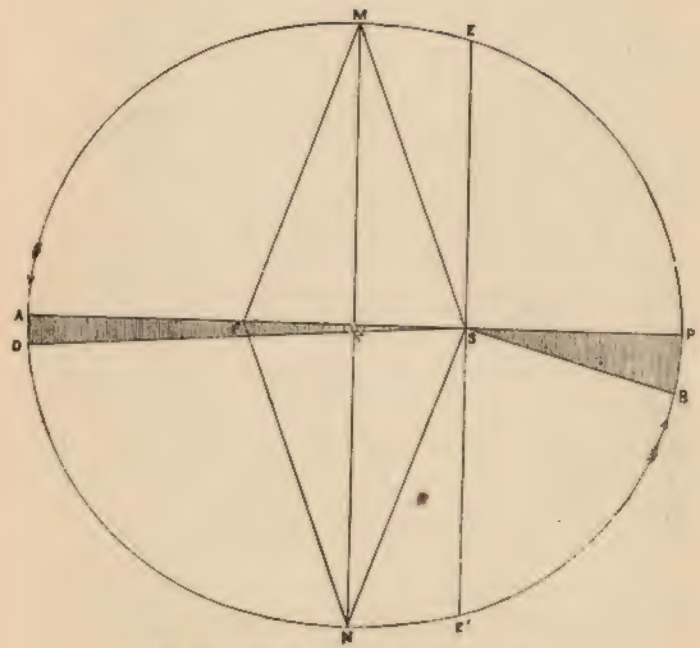



FIG. 7.—MOTION IN AN ELLIPTIC ORBIT.

foci) from the centre of the ellipse is (92,890,000 divided by 60, or) about 1,550,000 miles. Now if we subtract this from the mean distance, we obtain 91,340,000 miles from the earth's least distance from the sun, and if we add it, we find 94,440,000 miles for the earth's greatest distance from the sun. This difference, it will be seen, amounts to over 3 millions of miles, so that at one time of the year we are 3 millions of miles nearer to the sun than at the opposite point of the earth's orbit. The point of nearest approach is called the *perihelion*, and the point of greatest distance the *aphelion*. See diagram (fig. 7), which represents an ellipse of which the foci are S and F. Let S represent the focus in which the sun is situated. Then P will be the *perihelion*, and A the *aphelion*, CS the eccentricity, and SM=CP the mean distance. It is evident that SP, the perihelion distance, will be equal to CP—CS, and SA, the aphelion distance, equal to AC+CS, or CP+CS. The eccentricity of the ellipse shown in the diagram is considerably greater than that of the large planets, but is about the same as that of the minor planet. Polyhymnia (No. 33), the eccentricity of whose orbit is about 0.34 (or about one-third of the semi-axis major) as in the diagram.

It might be supposed that our nearest approach to the sun would occur in summer, but curious to say we are 3 millions of miles nearer the sun in December than in June.

This seems at first sight an extraordinary fact, but



in reality the difference of distance has little or nothing to do with the heat of the summer and the cold of winter. The difference of temperature is really due to the difference in the height of the sun above the horizon, and the length of the day. In the summer the days being very long, and the nights short, the earth and air are heated for a longer time than they are cooled during the night. The reverse of this takes place in winter.

The other planets also move in elliptical orbits round the sun, and all move in accordance with three laws which were discovered by the famous astronomer, Kepler, in the 17th century, and which are called "Kepler's Laws." The first of these laws is that which we have just considered, namely, that all the planets revolve round the sun in ellipses, the sun being situated in one of the foci. The second law is that the *radius vector*, or line joining the sun and planet, *describes equal areas in equal times*. The third law is, "*the squares of the periodic times are proportional to the cubes of the mean distances from the sun.*"

In the diagram (fig. 7) the *radius vector* is represented by SP, SM, or SA. The length of the *radius vector* depends upon the distance of the planet from the sun at any time. Now, the velocity at "perihelion" P is greatest, and that at "aphelion" A least. If in the diagram BP represents the arc traversed near perihelion in any given time, then near aphelion the distance described in the *same* time will be an

arc AD of such a length as to make the area ASD equal to the area PSB. This is true for every point in the orbit, the velocity varying so as to make the area swept over by the *radius vector a constant quantity for equal times.*

The time occupied by the planet in moving from E′ through P to E will be less than in moving from E through A to E′, as the area E′PE is less than the remainder of the ellipse. For this reason the winter in England is somewhat shorter than the summer.

To give an illustration of the third law of Kepler. Take the case of the earth and Mars. The periodic times are about 365 and 687 days, and the mean distances from the sun are in the proportion of 1 and 1·5237 respectively. Then we have the proportion—

$$365^2 : 687^2 :: 1^3 : (1{\cdot}5237)^3$$
$$\text{or } 133{,}225 : 471{,}969 :: 1 : 3{\cdot}5375 \text{ nearly.}$$

Let us now consider the cause of the seasons. I explained in a former chapter that if a perpendicular be supposed drawn through the centre of the earth perpendicular to the plane of the ecliptic, then the earth's axis is inclined at an angle of 23½ degrees to this line, or at an angle of 66½ degrees to the plane of the orbit (the ecliptic). See fig. 6. To this inclination all the seasons of the year are due. If the axis of the earth were perpendicular to its orbit, it will be easily seen that the days and nights would be of equal length all over the earth, and at all times of the year. The earth's position with reference to the sun would then always remain the same, and

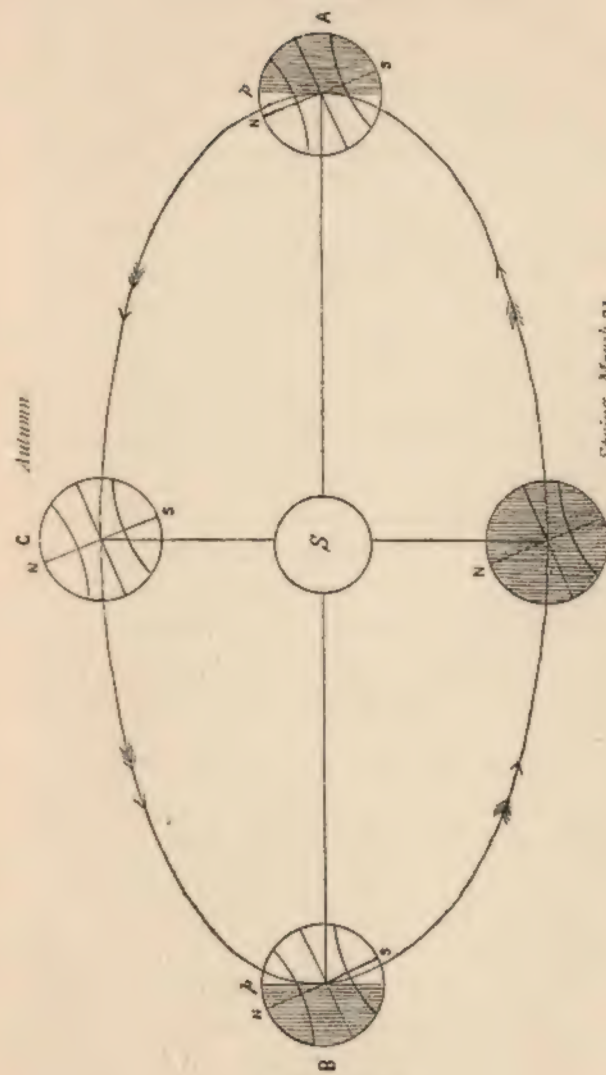



FIG. 8.—THE SEASONS.

there would then be no seasons. But as the earth's axis is inclined to the plane of its orbit, and always remains parallel to itself (always pointing to the celestial pole), it will be seen from the diagram (fig. 8), which is a perspective view of the earth's orbit round the sun, that at one season of the year the northern hemisphere is inclined *towards* the sun, and 6 months after is inclined *away* from the sun. In the southern hemisphere of course the same thing occurs, but in summer, when the North Pole is turned towards the sun, the South Pole is inclined away from it, and *vice versâ*. Hence, when it is summer in England, it is winter in Australia and countries south of the equator, and their summer is our winter. At the intermediate positions C and D both hemispheres are similarly situated with reference to the sun, and at these times—March 21st and September 21st—day and night are of equal length all over the earth. These are called—for this reason—the *equinoxes*.

The curved lines on the earth's figure in the diagram represent the tropics. It will be seen that at A in the regions north of the northern tropic—called the "tropic of Cancer"—the greater portion of the diurnal path falls in the illuminated portion, and the smaller portion in the dark part. North of a certain point *p*, the latitude of which is evidently 66½ degrees, there is no portion in the dark part, and here there is no night in summer. It is "the Land of the Midnight Sun." The reverse of this takes



place at B, where the whole region between *p* and the North Pole N is in the dark part, and then there is no day in those regions. The same thing occurs in the regions near the South Pole, but of course the seasons are there reversed, as at other places south of the equator.

The variation in the sun's distance will, however, have some slight effect on the temperature. It has this effect, that in the northern hemisphere the diminished distance of the sun in winter and the increased distance in summer mitigates, to some extent, the cold of winter and the heat of summer.

It will be seen from the diagram that in the southern hemisphere the summer occurs at the point of nearest approach to the sun or perihelion, and the winter occurs at aphelion. This will have the effect of *increasing* the summer temperature and diminishing the winter temperature, which is the reverse of what happens in the northern hemisphere.

Although the summer temperature of the southern hemisphere is greater than that of the northern, the total amount of solar heat received by each hemisphere during its summer season will be the same, for the following reason. When a planet, like the earth, revolves round the sun in an elliptical orbit, the velocity is greatest at the *perihelion* and least at the *aphelion*. Hence, as the English summer occurs at *aphelion*, when the earth is moving slowly, the summer will be somewhat longer than the winter. The reverse of this takes place in southern latitudes.

There the summer occurring at *perihelion*, the summer is *shorter* than the winter, and although the temperature shown by the thermometer is higher, it lasts for a shorter time, and the greater heat is counterbalanced by its shorter duration. At least this would be theoretically the case; but the effect is modified by other laws and local and geographical causes at different places.

But it may be asked, How is it known that the sun is nearer to the earth in the English winter than it is in summer?

This is very easily proved; for it is found that when the sun's apparent diameter is measured with astronomical instruments it is greater in winter than it is in summer, and the reader knows that the nearer an object is to the eye the larger it appears.

At the terrestrial equator there is but little change of seasons, for there the celestial equator passes through the zenith or point exactly overhead, so that on the 21st of June the sun is 23½ degrees north of the zenith, and on the 21st of December 23½ degrees south. The altitude, therefore, of the sun at noon is, on the earth's equator, never less than 66½ degrees, so that the inhabitants have a sort of perpetual summer. In fact, as the sun is on the celestial equator, or in the zenith twice a year, namely, on March 21st and September 21st, there are really *two* hot summers, with a milder summer between, and real winter is unknown.

## CHAPTER V.

### THE EQUATION OF TIME AND LEAP YEAR.

THE student will now understand the motions of the earth. The earth has a diurnal motion on its axis from west to east in about 24 hours, which produces the phenomena of day and night, and also the apparent daily motion of the sun, moon, and stars in the opposite direction, from east to west. In addition to this daily motion the earth has an annual motion round the sun, also from west to east, which produces the apparent motion of the sun among the fixed stars from west to east, and this motion, combined with the inclination of the earth's axis to the plane of its orbit, produces the changes of the seasons.

We will now proceed to consider the difference between *mean* time and *apparent* time. The earth is popularly supposed to rotate on its axis in 24 hours, but this is not exactly true. The correct period is 23h. 56m. 4s.

For the ordinary purposes of life it is found convenient to consider the day as the interval which elapses between two successive returns of the

sun to the meridian. If the sun were apparently fixed in the sky this interval would be exactly equal to the period of the earth's rotation, but, as you have learned, the sun has an *apparent* motion from west to east among the fixed stars. Hence, owing to this easterly motion, it will not come to the meridian exactly after one rotation of the earth, but a few minutes later. The solar day is therefore longer than the sidereal day (or period between two successive returns of the same star to the meridian). It is this solar day which is divided into 24 hours.

The length of the *solar* day is not, however, constant. It would be so if the sun moved along the celestial equator with a *uniform* velocity. But the sun does not move along the equator, but along the ecliptic, which is inclined to the equator, and its motion is not quite uniform, owing to the elliptic shape of the earth's orbit. In fact its apparent velocity is constantly varying to a small extent, being greatest in the English winter, and least in summer. The time shown by a sun dial is for this reason constantly varying.

The time shown by a sun dial is "apparent solar time," and a correction must always be made to the time found by such an instrument. This correction is called *the Equation of Time.* The result is called the "mean solar time."

This "equation of time" vanishes on four days of the year, namely, April 15th, June 15th, August 31st, and December 24th. I must explain, however, that for



astronomical purposes clocks are constructed to show "sidereal time," that is, the time which elapses between two successive returns of the same fixed star to the meridian. This period of 23h. 56m. 4s. is divided into 24 hours, so that a sidereal clock apparently "gains" nearly 4 minutes a day. But these clocks are only used in observatories.

I will now explain the necessity for a "leap year." The length of the year is not 365 days *exactly*, but about 365¼ days, or, more exactly, 365 days, 6 hours, 9 minutes, 9½ seconds. This is called the "sidereal" year. The mean "solar" or "tropical" year is the interval which elapses between the passage of the sun through an equinoctial point and back to the same point. Were the equinoxes fixed points in the sky the "solar" and "sidereal" years would be of exactly the same length; but as these points have —owing to a motion called the "precession of the equinoxes"—a slow movement from east to west, it follows that the equinoctial point moves to meet the sun, and therefore the "solar" year is shorter than the "sidereal." The length of the solar year is 365 days, 5 hours, 48 minutes, 46¾ seconds, or somewhat less than 365¼ days. To allow for this quarter-day one day is added every four years. This year is called Leap Year, and contains 366 days, the other three having only 365 days each. Every year divisible by 4 is a leap year.

The year is, however, not *exactly* 365¼ days, and this would cause some error in the course of time.

It would make a difference of about one whole day in 130 years, or about 3 days in 400 years. This is corrected by omitting a leap year at the beginning of each century, when the year—although divisible by 4—is not divisible by 400. Thus the years 1700, 1800, and 1900 are common years, but 2000 will be a leap year.

1900 will *not* be a leap year, although it can be divided by 4. 1896 will be a leap year, and then there will not be another till the year 1904.

This change in the method of reckoning was made in the year 1752 in this country, when the beginning of the year was also changed from March 25th to January 1st. It is called the "New Style." The "Old Style" ("O.S.") is still retained in Russia and Greece.

## CHAPTER VI.

### THE SUN.

HAVING now considered the earth and its motions, the student will like to hear something about the sun, moon, and the other planets which form with the earth, the Solar System.

The sun's diameter is about 866,000 miles, or about 109 times the diameter of the earth; and as the volumes of spheres vary as the cubes of their diameters, the sun's volume is about 1,300,000 times that of the earth, and its surface nearly 12,000 times greater.

The student may ask, Is the sun then more than a million and a quarter times the *weight* of a globe like the earth? No; the sun is much lighter than the earth in proportion to its size; in the same way that silver is much lighter than an equal volume of gold. Indeed the sun's density is very little more than ¼th of that of the earth, so that its mass, as it is termed, is only 332,000 times that of the earth.

The sun's mass is, however, *absolutely* very great.

It is more than 700 times the mass of all the planets and satellites put together.

The sun rotates on its axis like the earth. But the period of rotation is much longer—about 25¼ days. This is ascertained by watching the motion of spots on its surface.

The exact nature of these spots has not been well ascertained. Numerous theories have been advanced to account for these curious phenomena; but they are believed to be openings in the outer envelope of the sun, and are known to be most prevalent on the sun's surface every 11 years, and less numerous during intermediate years.

It was formerly believed that the solar light and heat were due to some form of combustion, but the enormous quantity of fuel necessary to support this combustion, and the great difficulty of explaining where this vast amount of fuel came from, has led astronomers to abandon the theory. How, then, is the expenditure of light and heat maintained? It is now almost generally admitted that the heat and light are due to the contraction or shrinkage of the solar mass. It may be shown mathematically that this shrinkage is quite adequate to produce the observed effects, and it certainly seems to be the most satisfactory theory which has yet been advanced. The theory is due to the eminent German physicist, Helmholtz, and has been ably supported by Sir William Thomson.

But, it may be asked, if shrinkage can produce



light and heat, to what cause is this shrinkage due? The answer to this is simple. The shrinkage is due to the immense attraction of the sun's great mass on its component particles, and owing to the comparatively small density of the sun this attraction is able to act more effectively on the sun's mass than it could do on the heavier materials which form our earth.

But, it may be said, if the sun is shrinking in this way, it must be gradually diminishing in size. Could not this diminution be detected by astronomical instruments? We might naturally fancy it could, but Sir W. Thomson, who ably advocates Helmholtz's theory, has shown that the shrinkage necessary to produce the observed amount of light and heat is so small that the diminution in the sun's apparent diameter, even in the long period of 2000 years, could scarcely be detected by our most accurate instruments. And of course we have no measurements of the sun's diameter dating nearly so far back as 2000 years.

This theory seems to be a simple and satisfactory one, and as we know that the enormous gravitating power of the sun *must* produce shrinkage in its mass, and that the shrinkage of a large mass *must* produce light and heat, there seems to be no necessity to look further for an explanation of the "mystery of the sun." In fact "the fuel of the sun" is no longer a mystery, and the solar light and heat find a satisfactory explanation in the "gravitation

theory." Of course the *cause* of gravitation itself still remains as great a mystery as ever.

Although the sun is *comparatively* close to us when compared with the immense interval which separates us from even the nearest of the fixed stars, still its distance is *absolutely* very great. Light with its enormous velocity of 186,000 miles per second, takes over 8 minutes to reach us from the sun. A cannon ball, moving with a velocity of 1,500 feet per second, would take over 10 years to traverse the distance, and a railway train, travelling at the speed of 60 miles an hour, would take about 176 years in its journey across the vast space which separates us from the solar orb.

## CHAPTER VII.

### THE MOON.

NEXT to the sun the moon is the most conspicuous object in the heavens, and being our nearest celestial neighbour forms of course an object of especial interest. Its diameter is about 2,160 miles, and its mean distance from the earth about 238,800 miles.

In addition to being an interesting and beautiful object, I have explained in a previous chapter that it is useful for finding the longitude at sea, as well as for giving light at night.

The division of time into months evidently had its origin in the period of the moon's revolution round the earth. This period is not exactly a calendar month, which is an arbitrary division of time. The period in which the moon moves from any point in the sky round to the same point again is 27 days, 7 hours, 43 minutes. This is called the *sidereal* revolution, but while the moon is performing its revolution round the earth, the earth itself is proceeding on its annual journey round the sun. For this reason the moon has to travel some

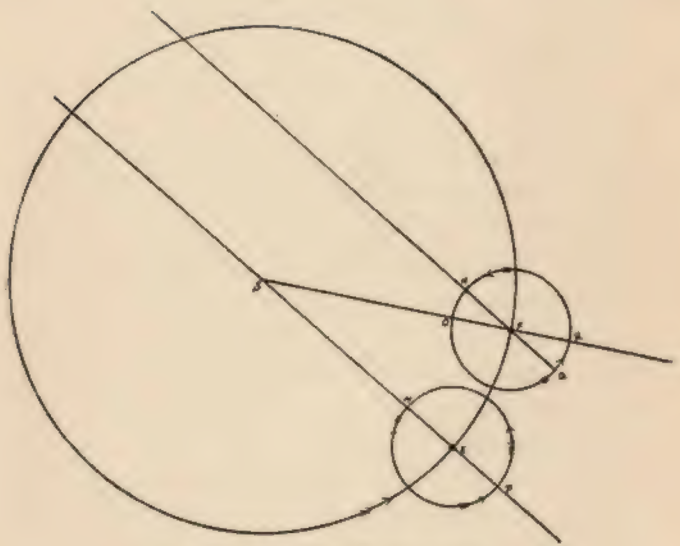


FIG. 9.—MOTION OF THE MOON.



distance further before it comes into the same relative position with reference to the sun and earth, and hence the period from new moon to new moon is longer, and amounts to 29 days, 12 hours, 44 minutes. This is called the *synodical* month.

I may, perhaps, make this point clearer by means of a diagram. In the diagram (fig. 9), if E represents the position of the earth, and S that of the sun, then M will be the position of the moon at the time of "new moon." The arrows show the direction of motion of the moon round the earth, and of the earth round the sun (opposite to that of the hands of a watch). Now in the course of one revolution of the moon, the earth will have moved from E to F, while the moon will have moved round to a point N, so that FN is parallel to ES (and therefore directed to the same point among the stars). But to come into the position of "new moon" again the moon must move on to O, or a distance NO greater than the circumference of its orbit round the earth. For this reason the "synodical" month is longer than the "tropical."

The same thing applies to the "full moon," as will be seen by examining the diagram. P is the position of "full moon," when the earth is at E, and R the position of "full moon" when the earth is at F. Hence the moon starting from the point P, has to complete a full revolution, and in addition a distance QR equal to NO.

Let us now consider the different phases of the

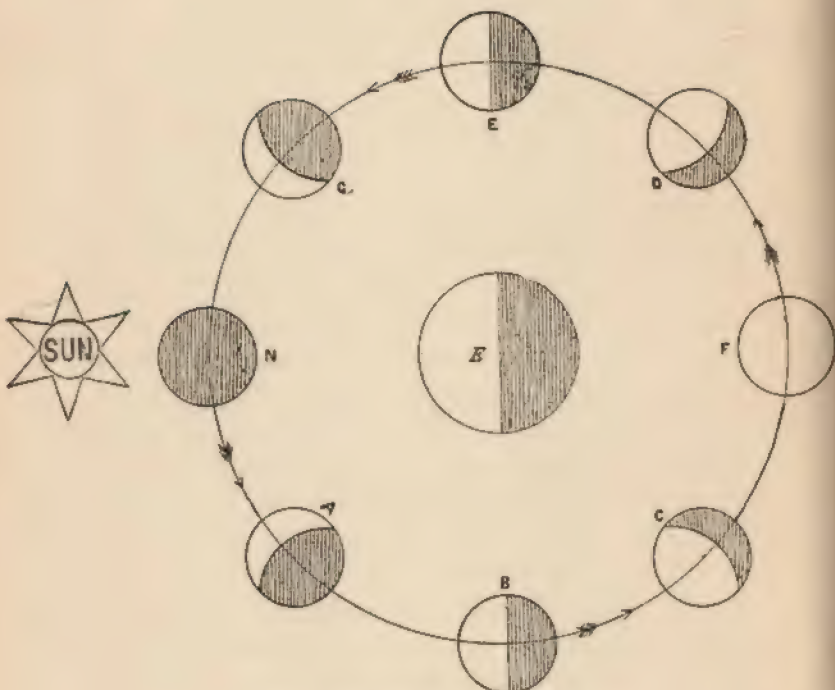



FIG. 10.—PHASES OF THE MOON.



moon. In the diagram (fig. 10) let E represent the earth, S the sun, and suppose the moon to revolve in the direction of the arrows. Then neglecting the earth's motion round the sun (which will not affect the explanation); when the moon is at N, between the earth and S, its illuminated side is turned towards the sun, and its dark side towards the earth. In this position it becomes invisible, and is called "new moon." When it advances to the point A, a portion of the illuminated side becomes visible in the form of a crescent, and when it arrives at the point B, half the moon is visible. It is then said to be in *quadrature* (because the angle between the sun and moon is then a right angle) or in popular language the "First Quarter." When it reaches the point C, more than half the illuminated side comes into view, and it is then said to be *gibbous*. At F, directly opposite to the sun, or in *opposition*, we see the full disc, and it is then called "Full Moon." Still proceeding in its course these changes are repeated in inverse order, being "gibbous" at D, in "quadrature" at E, called "Last Quarter"; and in the crescent shape again at G, a few days before "New Moon." After "new moon," as it appears to the left (or east) of the sun at A, the crescent is seen in the evening after sunset; and at G before "new moon," being to the right (or west) of the sun, the crescent is seen in the morning before sunrise.

But it may be asked, How is it that we only

see one side of the moon? This is due to the fact that the moon rotates on its axis in the same time that she revolves round the earth (see fig. 11). But it is not strictly true that we never see any portion of the opposite hemisphere. Owing to the slightly elliptical shape of the moon's orbit her motion round the earth is not quite uniform, while her rotation on her axis is perfectly so. This gives rise to a phenomenon called *libration*, which sometimes brings a portion of the further hemisphere into view, near the east and west limbs.[1]

If we represent the whole spherical surface by 1, the area of the portion which always remains invisible will be 0·4111, or about 41 per cent. Or in other words, if the whole surface be represented by 100, then 41 will represent the part permanently invisible, and 59 the portion known to observers.[2]

When the moon is a crescent the student may have often seen the dark side, when the air is clear. This is simply due to sunshine reflected from the earth, or "earthshine," as it is sometimes called. The earth is very much larger than the moon, and consequently, as seen from the moon, the earth would appear very much larger than the moon appears to us. In fact it would appear about

[1] There is another small libration which brings portions near the poles into view.

[2] Taking the moon's diameter at 2,160 miles, we have the total area of its surface, 14,657,407 square miles, and hence the area which remains permanently invisible will be 6,025,660 square miles.

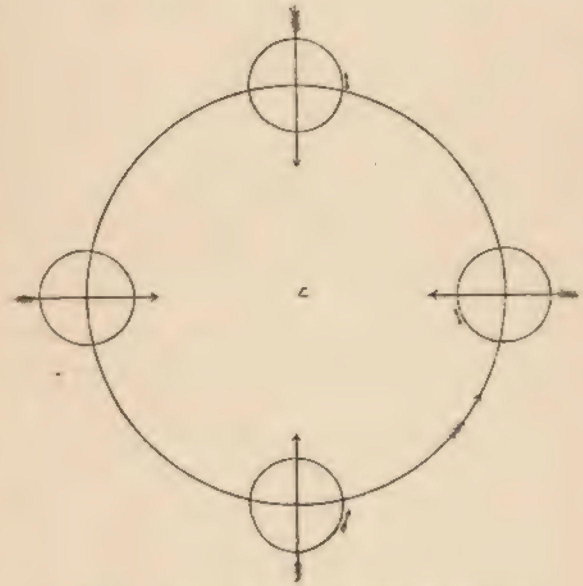


FIG. 11.—ROTATION OF THE MOON ON ITS AXIS.

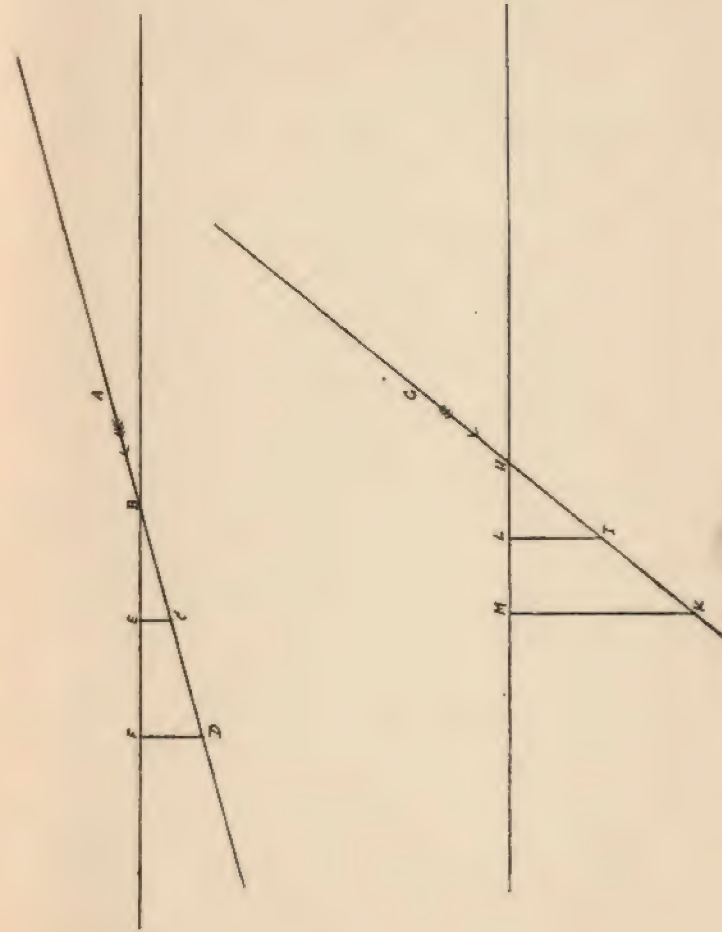
13 times as large, and therefore gives considerably more light to the moon than the moon does to us.

The earth as seen from the moon would show similar phases; with this difference, that when the moon is "full" to us the earth is "new" to the moon, and at "new" moon the earth is "full." Now it is clear why the dark side is faintly visible a little after "new moon," for the earth is then nearly "full" to the moon, and lights up its surface much more brilliantly than full moonshine on the earth.

The existence of any forms of life on the moon's surface is very improbable. Observations show that the moon is devoid of air and water, which are absolutely necessary to most forms of life. If it has an attenuated atmosphere, it is so rarefied that its existence cannot be detected by our most delicate observations.

The phenomenon of the "harvest moon" is familiar to most people. This is best explained by reference to a celestial globe, but I will try and make the matter clear in another way. The "harvest moon" is the full moon which occurs on or *nearest* to the 21st of September (the autumnal equinox), and is so called because it is useful at that season in the evenings for getting in the crops. The moon being then in the sign Aries,[1] rising due east, and the

[1] Owing to the "precession of the equinoxes" the "sign" Aries is now in the constellation Pisces, and the sign Libra in Virgo.



FIGS. 12, 13.—TO ILLUSTRATE PHENOMENON OF HARVEST MOON.

sun entering Libra, and setting due west, the southern half of the ecliptic is then above the horizon, and the northern half below it, and the ecliptic then makes the smallest possible angle with the horizon. Now the moon moving nearly in the ecliptic its rising is less retarded for several days than at other times. Perhaps a diagram will make the matter clearer. In fig. 12, let A, B, C, D represent the position of the moon on four consecutive days at the time of harvest moon (FEB the horizon), and in fig. 13, let G, H, I, K represent its position on four consecutive days, when its apparent path in the heavens makes a larger angle with the horizon MLH. Then it is evident that the spaces through which it must rise at C and D, namely CE and DF, are much less than the corresponding spaces IL and KM in the second figure. The distances AB, BC, CD are equal, and each equal to GH, HI, and IK. Hence the time of rising in fig. 12 is much less delayed than in fig. 13.

At the equator, as the north and south poles are on the horizon, the ecliptic makes the same angle with the horizon at the vernal and autumnal equinoxes, so the phenomenon of the harvest moon is not apparent. Indeed, at the equator the harvest moon is not required. The further north we go the more marked is the phenomenon.[1]

The student may have noticed that in winter the

[1] Of course, within the arctic and antarctic circles the moon remains constantly above the horizon during the winter.



moon is high in the heavens, and in summer is low down near the southern horizon. This is due to its path lying near the ecliptic, which is high in winter and low in summer. In winter when its light is most required it is high in the sky, and in summer when the bright nights render moonlight unnecessary it is low. In this will clearly be seen the evidence of Divine wisdom.

# CHAPTER VIII.

## ECLIPSES.

ECLIPSES of the sun and moon are very interesting phenomena, and are of tolerably frequent occurrence (especially those of the moon). I will begin with those of the sun, as the nature of these is very simple. An eclipse of the sun is caused by the moon passing between the sun and earth.

This evidently can only occur at "new moon," when the moon is between the sun and earth. But it may be asked, How is it that an eclipse of the sun does not happen at every full moon? This is due to the fact that the moon's orbit is inclined to the ecliptic at a small angle (about $5\frac{1}{7}$ degrees). For this reason the moon generally passes either a little above or a little below the sun at the time of new moon.

Under what circumstances, then, can an eclipse of the sun occur? The moon's orbit intersects the ecliptic at two points which are called the *nodes*. When the new moon occurs in or near one of these nodes an eclipse of the sun takes place.



The apparent diameter of the moon is not always the same as that of the sun. Owing to the elliptical shape of the orbits of the earth and moon, the moon's apparent diameter is sometimes greater and sometimes less than that of the sun. When the moon is at her greatest distance from the sun, and her apparent diameter consequently at its smallest, if it happens to be *in* the node at the time of new moon we have the phenomenon known as an "annular eclipse," a narrow ring of sunlight being visible all round the moon's black disc. When the moon is nearest to the earth and in the node, we have a *total* eclipse of the sun—a phenomenon of very rare occurrence, at least in Great Britain. In all other cases the eclipse is only a *partial* one.

A total eclipse cannot last long. Under the most favourable conditions the duration of the total phase cannot much exceed 7 minutes, and it is generally considerably less than this.

The last total eclipse visible in England took place on May 22, 1724, and the next will not happen till August 11, 1999,[1] when the sun will be totally eclipsed for about two minutes in the south-east of England, at Plymouth, Torquay, Weymouth, &c. An "annular" eclipse will be visible from the Shetland and Orkney Islands on April 8, 1921.[1]

[1] See "Eclipses and Transits in Future Years," by the Rev. S. J. Johnson, M.A., F.R.A.S. (Parker and Co., Southampton Street, Strand). The solar eclipse of June 29, 1927, will be total for a few seconds in the north of England.

The next solar eclipse of any magnitude visible in England will occur on May 28, 1900, when seven-tenths of the sun's disc will be eclipsed in the south of England.

A total eclipse of the sun is one of the grandest and most imposing sights in Nature. During the total phase a ring of light with rays is seen round the moon's disc. This is called the solar "corona," and is a glowing appendage surrounding the sun, which, owing to the intense glare of sunlight, is not visible on ordinary occasions.

An eclipse of the moon is caused by the moon passing through the earth's shadow, and can of course only occur at "full moon," when the sun, earth, and moon are in the same straight line. This does not happen at every "full moon," for the same reason that a solar eclipse does not occur at every "new moon," namely, the inclination of the moon's orbit to the plane of the ecliptic, which enables it to pass sometimes above and sometimes below the shadow of the earth.

A lunar eclipse lasts much longer than a solar one.

During an eclipse of the moon a lunar spectator would see the sun eclipsed by the earth's disc, which appears about 13 times larger than the moon does to us. It can therefore hide the sun for a much longer time. Another way of explaining the matter is that the diameter of the earth's shadow at the moon's distance is very considerable, so that the moon takes a long time to pass through it. For a

FIG. 14.—ECLIPSE OF THE MOON.

sphere, when the source of light is a globe larger than the sphere (as in the case of the sun and earth) the shape of the shadow is always a cone. If the sun and earth were of the same size, the shadow would be a cylinder of infinite length, but as the sun is much the larger, the earth's shadow is a cone, as will be seen by the accompanying diagram (fig. 14, which is of course not drawn to scale, but merely intended to represent the general principle of a lunar eclipse). S represents the sun, E the earth, and M the moon. The darkly shaded triangle represents the conical shadow, which is called the *umbra*, and the lighter shade is called the *penumbra*. Within the conical shadow the whole of the sun's disc is hidden from the moon, but in the *penumbra* a portion of the sun's disc only is eclipsed, as will be seen by the lines touching the edges of the sun and earth. Thus, if from any point P, within the penumbra, a line PC, parallel to AD, be drawn, touching the earth's surface and meeting the sun's surface at C, then to a spectator at P only the portion AC will be hidden by the earth, while the portion CB will remain uneclipsed. Hence there will be only a *partial* eclipse at P; and similarly for the other points within the limits of the *penumbra*.

From any given point on the earth's surface eclipses of the moon are more frequently *seen* than those of the sun; because when the moon is either partially or totally eclipsed, the eclipse is visible



from every point on the earth's surface from which the moon is visible at the time, but eclipses of the sun are only visible at certain points. In fact, an eclipse of the moon is a *real* eclipse, that is, a real darkening of the lunar surface, whereas those of the sun are merely occultations by the moon, and may be total in one place, and quite invisible at others. In reality, however, eclipses of the sun are more numerous than those of the moon. Out of 70 eclipses which usually occur in about 18 years, the average number of eclipses of the sun is 41, and of lunar eclipses 29.

The period of 18 years forms what is termed a "cycle," which was known to the ancient Greeks under the name of the *Saros*. During this period eclipses recur in nearly the same order.

As I have already explained, eclipses take place near the *nodes* of the moon's orbit, or the points at which the lunar orbit intersects the plane of the ecliptic. Now it is found from observation that these nodes do not maintain a fixed position, but have a rapid *retrograde* motion on the ecliptic [1] in a period of about 18½ years.[2] The apparent motion of the node is therefore in the *opposite* direction to that of the sun among the fixed stars. Consequently the sun, in its apparent annual motion through the heavens, will meet the same node in less than a

[1] Or contrary to the order of the signs of the Zodiac.

[2] The exact period of revolution of the node is 6793·391 days.

year, or in about 346·62 days. The moon's synodical revolution (or the period from one new or full moon to the next) is 29 days, 12 hours, 44 minutes. Now 223 of these periods amount to about 6,585⅓ days, while 19 periods of 346·62 days amount to 6,585¾ days. Hence it follows that at the end of this period, or about 18 years, 11 days, the sun, the moon, and the moon's node will return nearly to the same position with reference to each other, and consequently if an eclipse occurred at the beginning of the period, a similar, or nearly similar, eclipse will recur at the end.

Another cycle known to the ancient astronomers is termed the *metonic cycle*. This consists of 19 years of 365¼ days, or 6,939¾ days, which is very nearly equal to 235 synodical revolutions of the moon.

## CHAPTER IX.

### MERCURY.

HAVING now described the earth and moon, we will proceed to consider the other planets and satellites of the Solar System, commencing with Mercury, the nearest to the sun. Mercury and Venus, the two planets which revolve round the sun in orbits included *within* the earth's orbit, are termed "inferior planets."

It is known that these planets revolve *inside* the earth's orbit, from the very simple reason that they are found by observation to be constantly changing their places among the stars, and are never seen further from the sun than a limited distance. For example, if a man were to walk round a tree, placed in the centre of a circular enclosure, and a person standing at the boundary of the enclosure observed that the pedestrian was never seen in the opposite direction to that of the tree, he would conclude that his circular path round the tree was *included* within the boundary of the enclosure. For exactly the same reason the planets Mercury and Venus are

never seen in the part of the heavens opposite to the sun's place.

The greatest distance that Mercury can be seen from the sun, or the "greatest elongation"—as it is termed—of the planet cannot exceed 27¾ degrees, or less than one-third of the distance from the horizon to the zenith, and it rarely exceeds 18 degrees (or one-fifth of the same distance). For this reason the planet is seldom seen with the naked eye, being only visible in the morning and evening twilight.

The mean distance of Mercury from the sun is about 36 millions of miles, and the period of revolution round the sun—or the length of its year—is about 88 of our days. The orbit is, however, very elliptical, and for this reason the distance varies from about 27 millions to 43 millions of miles. Its orbit is inclined to the ecliptic at the angle of about 7 degrees.

Bessel supposed the period of rotation on its axis to be about 24 hours, but this is very uncertain. Professor Schiaparelli has recently announced his opinion, based on 10 years' observation, that the rotation is similar to that of the moon—that is, that the period of rotation on its axis is equal to the period of revolution round the sun, so that the planet always turns the same side towards the sun. This result, if confirmed, is certainly very interesting and unexpected.

The diameter of Mercury is about 3,000 miles, so that in volume it is the smallest of all the large primary planets.[1] But in density it is very heavy—about 7 times the weight of water (that of the earth being about 5½).



Owing to the intense heat of the sun we cannot suppose it to be inhabited by any forms of life, except perhaps close to the poles of the planet; or, if Schiaparelli's theory be correct, near the boundary line dividing the light from the dark side.

Mercury, seen with a telescope, shows phases similar to those of the moon, which proves that it shines—like the moon—by light reflected from the sun. Its apparent motion among the fixed stars resembles that of Venus, and this I will explain when speaking of that planet.

Mercury occasionally passes across the sun's disc like a small black spot. The last transit of Mercury occurred in November, 1881, and the next will take place on May 10, 1891, and November 10, 1894. These transits can of course only occur when the planet is in that portion of its orbit which lies beween the earth and the sun, or when the planet is in *inferior* conjunction, as it is termed. When the planet passes behind the sun it is said to be in *superior* conjunction.

The student may ask, How is it that a transit does not occur at *every* inferior conjunction? For the same reason that an eclipse of the sun does not take place at every new moon, namely, that the orbit of

[1] All the "minor planets," revolving between Mars and Jupiter, are, however, much smaller.

Mercury is inclined to the ecliptic, and consequently the planet sometimes passes a little above the sun, and sometimes a little below it, when in conjunction. A transit can only occur when the planet is in or near its node (or inclination of its orbit plane with the plane of the ecliptic), and this rarely occurs.

## CHAPTER X.

### VENUS.

NEXT to Mercury comes the brilliant planet Venus, which is often seen in the evening sky after sunset. It is the brightest of all the planets, occasionally so bright as to cast a shadow on a white surface!

It is considerably larger than Mercury, and but little smaller than the earth, its diameter being about 7,700 miles (the earth's mean diameter being 7,912). It revolves round the sun at a mean distance of 67 millions of miles, in a period of about 225 days. Its period of rotation on its axis is supposed to be about 23¼ hours, but this is doubtful,[1] owing to the difficulty of seeing any well-defined markings on its surface. The position of the axis of rotation is still more uncertain.

The "greatest elongation" of Venus from the sun can never exceed about 47 degrees, or about half the distance from the horizon to the zenith.

[1] Schiaparelli is of opinion that Venus—like Mercury—rotates on its axis in the same time that it revolves round the sun.

Venus sometimes appears brighter than at others. This is due to its varying distance from the earth. When it is near "inferior conjunction," or nearly between the earth and sun, its distance from the earth is only 26 millions of miles,[1] whereas when in "superior conjunction," or on the other side of the sun, its distance is about 160 millions of miles,[2] or its greatest distance is about 6 times its least distance. When near its least distance, however, it shows a thin crescent as the moon does when near the sun, whereas when near its greatest distance it exhibits a full face, so that its brilliancy is not so greatly diminished in the latter case as its increased distance in this position might at first sight lead us to expect.

I said in the last chapter that I would explain the apparent motion of Mercury and Venus among the fixed stars. At first sight the apparent motion seems somewhat complicated, but it really admits of a simple explanation, as will be seen by studying the accompanying diagram (fig. 15), which is carefully drawn to scale (supposing the orbits to be circular, as they nearly are). A, B, C, D, &c., represent successive positions of the earth at intervals of 10 days, and A′ B′, C′, D′ the corresponding positions of Venus. The outer circle is supposed to represent the star sphere, and *a*, *b*, *c*, *d*, &c., are the successive positions of the planet as seen from the earth at A, B, C, D, &c., respectively; S being the position of the sun, and the arrows representing the direction of motion.

[1] 67 deducted from 93. [2] 67 added to 93.



A′ is the point of "greatest elongation" as seen from the earth's position at A, the angle AA′S being a right angle (and AA′ a tangent to the orbit of Venus at A′). As the small letters *a*, *b*, *c*, *d*, &c., representing the apparent positions of Venus among the stars, are in alphabetical order, an examination of the diagram will show that the apparent motion of the planet is *direct* from *a* to *e* (or in the order of the signs). At some point between *e* and *f* the direct motion ceases, and the planet becomes, for a short time, stationary,[1] and afterwards retrograde, so that when the earth arrives at F (and Venus at F′) the planet has retrograded to *f*. This retrograde motion continues through inferior conjunction (HH′h) up to a point near L, where the planet again becomes stationary, and the motion, shortly after, again *direct*, and this direct motion is maintained through "superior conjunction." From A to H Venus is an evening star, and from I to N a morning star.[2] Its varying distance from the earth will be seen from the diagram, AA′ being considerably greater than HH′, where the planet is nearly at its minimum distance.

[1] In some text books on astronomy it is stated that a planet is *stationary* when it is moving nearly in a line towards an observer on the earth. This is, however, quite incorrect. At the point A in the diagram Venus is moving directly towards the earth, but it is not then stationary; on the contrary, it has at this point a *rapid direct motion*.

[2] Of course the planet would have been an evening star for a considerable time before it reached the point A′, and remains a morning star for a long time after it has passed the point N′.

The student may have heard of transits of Venus being employed to find the sun's distance from the earth. The actual details of the calculation are very complicated, but the general principle of the method is sufficiently simple, and will be easily understood. In the diagram (fig. 15) illustrating the relative motions of the earth and Venus, it will be seen that when the planet is at its greatest elongation at A′, if we measure the angle of elongation SAA′, which can be easily done, we can (since the angle at A′ is a right angle) find, by the rules of plain trigonometry, the ratio of SA′ to SA. Now SA′ is the distance of Venus from the sun, and SA is the earth's distance from the sun. The ratio of these distances can therefore be found by observation and simple calculation.[1] (It could also be determined by Kepler's third law.)

When Venus is projected on the sun's disc during a transit, its apparent position as seen from stations widely separated on the earth's surface may be ascertained by careful observation, and the observed displacement enables us to calculate the sun's distance from the earth, as will be seen from the accompanying diagram (fig. 16). Let A be a station in the earth's northern hemisphere, and B a station in the southern hemisphere, separated by a diameter of the earth.

[1] $\frac{SA'}{SA}$ = sin SAA′. Hence if we make SA = 1, we have S′A = sin SAA′. The relative distance of Venus and the earth being about 67 and 93 we have $\frac{67}{93}$ = 0·7204 = sin SAA′, and therefore SAA′ = 46° 5′ approximately.

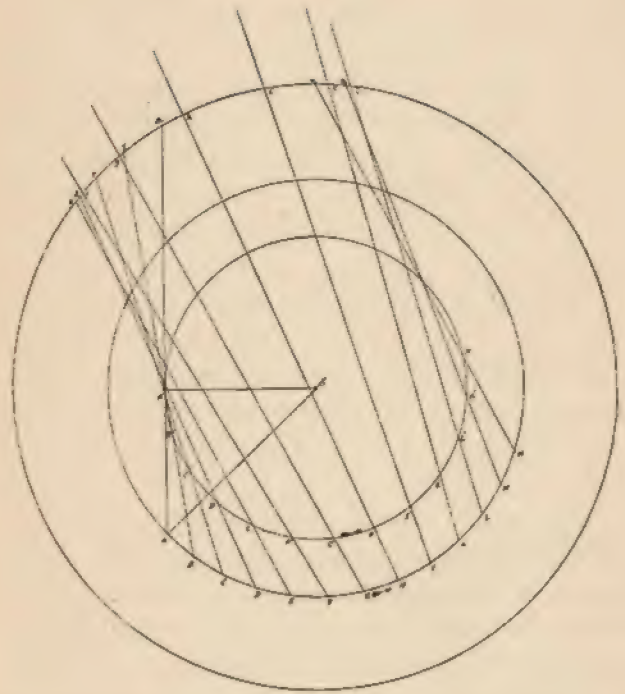


FIG. 15.—RELATIVE POSITIONS OF THE EARTH AND VENUS FROM GREATEST "ELONGATION" OF VENUS, THROUGH INFERIOR CONJUNCTION.

Then seen from A the centre of Venus, C, will be projected on the sun's disc at D, and seen from B it will appear at E.[1] Hence the total apparent displacement is ED. Now the alternate angles at C are (by Euclid) equal, and therefore ED is to AB as CD is to AC. But the latter ratio is about 67 to 26. Hence ED is about $2\frac{1}{2}$ times AB, and therefore the angle subtended by ED at the earth is about $2\frac{1}{2}$ times the angle subtended by AB at the sun. From this, knowing AB, the sun's distance from the earth can be found.

The distance ED may be found by noting the exact times at which Venus, moving in its orbit in the direction of the arrow, enters the sun's disc at F and H ("ingress") and leaves it at G and K ("egress"). From these intervals of time the lengths of the lines FG and HK may be found, and hence the value of ED may be computed.

This process is, in theory, simple enough, but in practice several corrections must be made before the necessary accuracy is attainable. For instance, the exact motions of Venus and the earth in their orbits during the transit, the rotation of the earth on its axis, &c., must be taken into account, and these details make the calculations complicated and troublesome.

Transits of Venus only occur after long intervals,

[1] The apparent displacement is of course greatly exaggerated, as the relative sizes of the earth, Venus, and the sun are not drawn to scale.

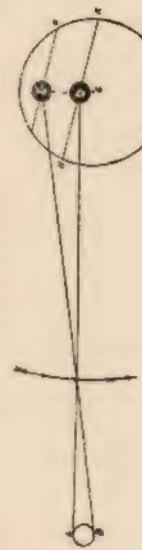


FIG. 16.—TRANSIT OF VENUS.

and then usually in pairs. These intervals are 8, 122, 8, 105, 8, 122 years, &c. The last pair occurred on Dec. 8, 1874, and Dec. 6, 1882, and the next two will not take place till June 7, 2004, and June 5, 2012. I had the good fortune to see both the transits in 1874 and 1882 myself. The former I observed in India, and the latter in the West of Ireland. Both were seen in a clear sky.[1]

[1] "Planetary and Stellar Studies," p. 32.

## CHAPTER XI.

### MARS.

NEXT to Mercury and Venus, in order of distance from the sun, comes our own earth, but as we have already discussed its dimensions and motions, we will now pass on to the "red planet" Mars, which is the next planet outside the earth. It revolves round the sun in a period of about 687 days, at a mean distance of about 141 millions of miles. The shape of its orbit is, however, more elliptical than that of the earth (see fig. 17). For this reason it is sometimes much nearer to the earth than at others, and consequently varies considerably in brilliancy at different oppositions.

Mars is larger than Mercury, but considerably smaller than the earth and Venus. Its diameter is about 4,200 miles, so that in volume the earth is about 6½ times larger.

It rotates on its axis, like the earth and the other planets, and the period of rotation, or the length of

its day, has been determined with great accuracy from observations of markings on its surface. The latest and most reliable computation makes this period 24 hours, 37 minutes, 22.66 seconds, so that the length of the day in Mars is known to within a tenth of a single second!

Mars is sometimes stationary among the stars, and sometimes retrograde, as in the case of Venus. This will be understood from the accompanying diagram (fig. 17). Starting from A, when Mars at A′ is seen in the sky at *a*, forming a right angle with the sun at S (or in "quadrature," as it is termed), the relative positions of the earth and Mars are shown at intervals of 10 days (as in the diagram of Venus). It will be seen that the lines joining the positions of the earth and Mars seem to *radiate* outwards from A to I, at which point they become nearly parallel, and afterwards apparently *converge* to the point O, when they again become parallel, and then again radiate outwards to the point X (when Mars is again in quadrature). Now, as parallel lines drawn from any two points in the earth's orbit to meet the celestial sphere point to the same star (owing to the immense distance of the stars), the radiation of the lines AA′*a*, BB′*b*, CC′*c*, &c., *outwards* shows that in these positions Mars has a *direct* motion among the stars. When the lines become parallel, near I, the planet becomes for a short time *stationary*, and when they converge, between J and N, the planet has an apparent *retrograde* motion. After passing OO′, the lines PP′*p*,

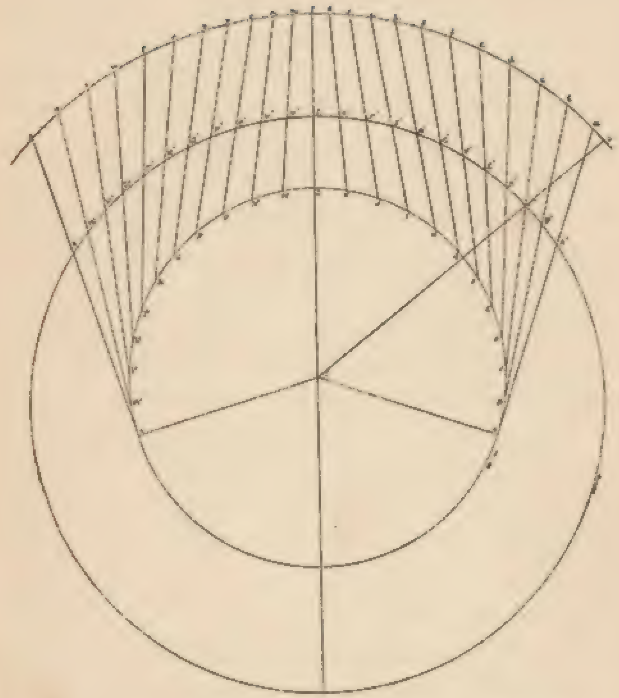


FIG. 17.—RELATIVE POSITIONS OF THE EARTH AND MARS BEFORE AND AFTER "OPPOSITION" OF MARS.

QQ$'q$, RR$'r$ again radiate outwards, and the planet's motion again becomes *direct.*[1]

Near the "quadratures" ($a$ and $x$ in the diagram) Mars is not seen with a full face—owing to the relative positions of the planet and the earth. At these points the planet appears somewhat "gibbous" in shape, like the moon a few days before and after full moon.

I may here explain the meaning of the terms *geocentric* and *heliocentric* place of a planet. The *geocentric* place is the apparent position as seen from the earth (or rather the earth's centre), and the "*heliocentric*" place its position as seen from the sun (or rather the sun's centre). For example, in fig. 17 the geocentric place of Mars at C$'$ is $c$, but its heliocentric place is $s$. At the point L$'$ the "geocentric" and "heliocentric" places are the same. When the planet is in "opposition," the sun, earth, and planet are then in the same straight line, or nearly so, and then the "geocentric" and "heliocentric" places coincide.

I spoke of "markings" on the disc of Mars. These markings are considered—and with great probability—to indicate the existence of land and

[1] In some text books on astronomy it is erroneously stated that a superior planet (like Mars) will appear *stationary* when the earth is advancing directly towards the planet. An inspection of fig. 17 will show that at the point A the earth is advancing *directly* towards Mars, and at X *directly* away from it. But at these points the planet is *not* stationary, but in *direct* motion. At the real stationary points, near I and O, the earth is *not* moving straight towards the planet.



water on the surface of the planet. Elaborate maps have been made of Mars on this supposition, showing various continents and oceans. If this view be correct —as it probably is—the areas of land and water on the planet are about equal. This is a different arrangement to that of the earth. On the earth the water surface is about 3 times as great as that of the land.

For many years Mars was supposed to have no moons, and Tennyson speaks of "the snowy poles of moonless Mars." Two very small satellites were, however, discovered in 1877 by Prof. Asaph Hall with the 26-inch refractor of the Washington Observatory. These are supposed to be about 6 and 7 miles in diameter. The inner moon has been called Phobos, and the outer one Deimos. Phobos is distant from the centre of Mars only 6,000 miles, and revolves round its primary in the unusually short period of 7 hours, 39 minutes. The distance of Deimos is about 15,000 miles, and its period of revolution about 30 hours, 18 minutes. These minute moons are among the smallest members of the Solar System.

## CHAPTER XII.

### THE MINOR PLANETS.

BETWEEN Mars and Jupiter a number of very small planets revolve round the sun. The orbits of many of these are very elliptical in shape, much more so than those of the larger planets. The first of these interesting discoveries was Ceres, which was found by Piazzi at Palermo on the first day of the present century, Jan. 1, 1801. In 1802 Olbers discovered Pallas. In 1804 Juno was found by Harding, and in 1807 Vesta by Olbers. No more were detected till 1845, when Astræa was discovered by Hencke, and in 1847 Hebe, by the same observer. Since that time yearly additions have been made to the list, and up to the present (October, 1890) no less than 299 have been found.

Vesta, the brightest of all, has been occasionally seen with the unassisted vision. Ceres may be seen with a good opera-glass, when favourably situated; but the great majority are only visible with a telescope.

The eminent astronomer Stone thinks that the



diameter of the first 71 minor planets varies from 60 to 214 miles. The fainter ones are of course probably still smaller, and Le Verrier has shown that the mass of all combined cannot exceed one-fourth of the earth's mass.

The orbits of some of them are inclined at a considerable angle to the plane of ecliptic. For instance, the orbit of Pallas has an inclination of nearly 35 degrees, those of Euphrosyne and Istria about 26½ degrees, Gallia nearly 26 degrees, and Æthra about 25 degrees. Others, however, have only a small inclination. Their orbits also intersect each other in a curious way, very different from those of the larger planets, which — when even at their nearest — are separated by a considerable distance.

## CHAPTER XIII.

### JUPITER.

We next come to the "giant planet" Jupiter, the largest member of the Solar System, exceeding in volume all the other planets put together.

Jupiter is much larger than Venus, but owing to his much greater distance from the earth and sun he appears fainter. His mean diameter is about 87,000 miles, so that in volume he exceeds the earth about 1,373 times, and Venus about 1,490 times. In density, however, Jupiter is much lighter than either the earth or Venus, its specific gravity (water equal 1) being only 1·30, that of the earth being 5·67, and Venus about 4·82.

The mean distance of Jupiter from the sun is about 483 millions of miles, and it revolves round the solar orb in a period of 11 years and 10 months.

Jupiter has a very rapid rotation on its axis for so large a globe, the period of rotation being about 9 hours, 55 minutes, 37 seconds. This gives a velocity at the planet's equator of about 8 miles a second! This velocity is about 28 times greater than the



speed of rotation at the earth's equator. This rapid rotation has been shown mathematically to explain the observed compression at the north and south poles of Jupiter's disc, which is very evident in a good telescope.

This compression is much greater than in the case of the earth, which is, as I said in a former chapter, nearly a sphere. The polar diameter of Jupiter is shorter than the equatorial diameter in the proportion of about 100 to 106½.

Jupiter is attended by four satellites or moons, which revolve round the planet in the same way that the planets revolve round the sun. One of them—the second in order of distance from the planet—is almost exactly the same size as the moon, its diameter being about 2,100 miles. The others are larger, No. I. being about 2,400 miles in diameter, No. III. 3,400, or somewhat larger than Mercury, and No. IV. about 2,900 miles. The following are their approximate distances from Jupiter, and periods of revolution round their primary:—

| Satellite. | Distance from Jupiter. | Period. | | |
|---|---|---|---|---|
| | MILES. | D. | H. | M. |
| I. | 274,000 | 1 | 18 | 39 |
| II. | 437,000 | 3 | 13 | 14 |
| III. | 697,000 | 7 | 3 | 43 |
| IV. | 1,226,000 | 16 | 16 | 32 |

The first satellite is therefore somewhat farther from Jupiter than the moon is from the earth, and the others at considerably greater distances. Like

our moon, these satellites apparently rotate on their axes in the same time that they revolve round their primary. The length of the day on Satellite I. is therefore 42½ hours, and on the others longer.

These satellites are subject to eclipse in Jupiter's shadow in the same way that our moon is eclipsed in the shadow of the earth ; but, unlike those of our moon, these eclipses are of frequent occurrence as seen from Jupiter. The reason of this is that the satellites revolve round Jupiter approximately in the plane of the planet's equator, which nearly coincides with the plane of its orbit (or "ecliptic," as we call it in the case of the earth).

The three inner satellites are eclipsed at every revolution, but the outer one, IV., occasionally escapes being eclipsed owing to the fact that its orbit is slightly inclined to those of the other satellites. A remarkable relation exists between the motions of the three inner satellites, from which it follows that all three can never be eclipsed together.

These eclipses are visible from the earth with the aid of a telescope, and the accompanying diagram (fig. 18) will illustrate the matter. S represents the sun ; P the planet throwing a dark shadow behind it ; A, B, C, D, E, F, G the earth's orbit, and *a, b, c, d* the orbit of one of the satellites, the arrows showing the direction of motion. Now when the earth is at A, and the satellite at *a*, it will enter the planet's shadow (called the *immersion*) and be eclipsed, as seen rom the earth. When it arrives at *b* it will emerge

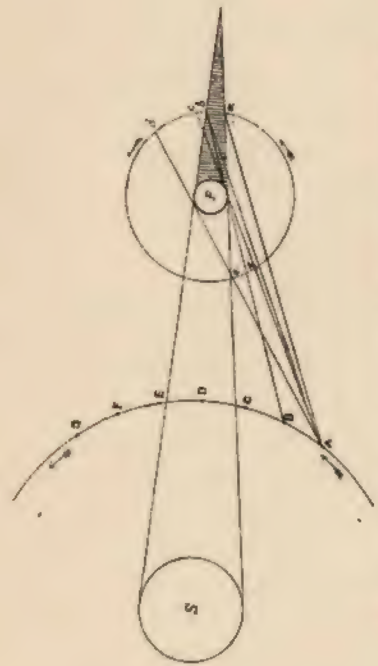


FIG. 18.—ECLIPSES OF JUPITER'S SATELLITES, AS SEEN FROM THE EARTH.

from the shadow (called the *emersion*). When it reaches *c* it will pass behind the planet's disc, as seen from A. This is termed an *occultation;* and when it arrives at *d* the satellite will reappear on the opposite side of the planet. In the position shown in the diagram Jupiter is seen to the right of the sun, and is then a morning star. The eclipses and occultations will then occur, as shown in the figure, or the eclipses first and the occultations afterwards. When the earth advances to G the planet will be an evening star, and the above phenomena will take place in reverse order, namely, the occultations first and the eclipses afterwards. Near D, when Jupiter is in "opposition" (rising at sunset), the occultations only will be visible, the eclipses occurring when the satellite is behind the planet. In the case of the first and second satellites, if the *immersion* can be seen, the *emersion* is invisible, and *vice versâ*. Another interesting phenomenon is the transit of a satellite across the disc of Jupiter. This occurs when the satellite is passing from *e* to *f*, as seen from A. In these transits the satellites are sometimes seen as black spots on Jupiter's disc. This seems curious, as they must be—in that position—fully illuminated by the sun's light. An attempt has been made to explain the fact by supposing that the planet possesses some inherent light of its own. A better explanation, however, seems to be that the apparent blackness of the satellites in transit is due to the difference in light reflecting power of Jupiter and the satellites—an effect of contrast in fact.



The surface of Jupiter is, however, very bright, not much inferior to that of white paper, and from *this* fact it seems very probable that the planet shines partly by inherent light—in other words, that its surface is red hot. It cannot, therefore, be inhabited, but its satellites may possibly form the abodes of some forms of life.

Most people have heard of Jupiter's "belts." These are darkish bands across its surface, as seen in a telescope, usually lying nearly parallel to the planet's equator, and generally of various shades of yellow and brown. They are not, however, constant features, their details being occasionally subject to rapid changes. Some astronomers consider that these "belts" represent the body of the planet seen through openings in its cloudy envelope.

# CHAPTER XIV.

## SATURN.

OUTSIDE Jupiter's orbit revolves the "ringed planet" Saturn, which, until the discovery of Uranus, was considered the outermost planet of the Solar System.

Its distance from the sun is much greater than that of Jupiter. Its mean distance is about 886 millions of miles, or about 9½ times the earth's mean distance from the sun. Its period of revolution is about 29½ years. As heat and light vary *inversely* as the square of the distance, we have the intensity of the heat and light received by the earth equal to 9·5 multiplied by 9·5, or about 91 times as great as Saturn experiences.

Saturn is a very large planet, but not quite so large as Jupiter, its mean diameter being about 72,000 miles, or over 9 times greater than that of the earth. As, however, the volumes of spheres vary as the *cubes* of their diameter it follows that Saturn exceeds the earth in volume about 797 times. In density, however, it is very light, its specific gravity being only 0·68 (water equal 1), that of the earth being 5·67. For this reason its mass (or quantity of matter) is



only 95 times greater than that of the earth. It has therefore little more than half the density of Jupiter. In fact it is the lightest planet of the Solar System, as far as we know at present.

Saturn is attended by eight moons, which have been named Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, and Japetus, in order of distance from the planet, Mimas being the nearest. Their distances from the centre of Saturn range from about 122,700 miles to about 2,350,000 miles, and their periods of revolution round their primary from about 22½ hours to 79 days, 7¾ hours.

Titan, the largest, is supposed to be about 3,300 miles in diameter, or a little larger than Mercury. The diameters of the others are somewhat doubtful, but the outer one, Japetus, is next in order of size. The two interior ones, Mimas and Enceladus, are very faint objects, and can only be seen in large telescopes.

According to Prof. Asaph Hall, Saturn rotates on its axis in 10 hours, 14 minutes, 24 seconds. It is, like Jupiter, considerably flattened at the poles, the ratio of the equatorial to the polar diameter being about as 12 to 11.

The rings of Saturn form the most unique and interesting feature in this wonderful system. They consist of two flat luminous rings, with a dark division between them, and enclosing a semi-luminous ring, known as the "dusky" or "crape" ring. These completely surround Saturn, but do not anywhere touch the planet. From some measures made in the years

1880–81 by Dr. Meyer at the Geneva Observatory I find that the exterior diameter of the outer ring is about 173,500 miles ; interior diameter of the middle ring, 112,440 miles ; interior diameter of dusky ring, 90,810 miles ; width between dusky ring and ball of planet, 7,632 miles. The width of the dark division between the bright rings, called Cassini's division—after its discoverer—is about 1,700 miles.

An eclipse of the satellite Japetus in the shadows of the globe, crape ring, and bright ring of Saturn, took place on Nov. 1, 1889. This interesting and rare phenomenon was well observed by Mr. E. E. Barnard at the Lick Observatory. His observations show that "the crape ring is truly transparent—the sunlight sifting through it. The particles composing it cut off an appreciable quantity of sunlight. They cluster more thickly, or the crape ring is denser as it approaches the bright rings. . . . So far as the penetration of the solar rays is concerned, the bright ring is fully as opaque as the globe of *Saturn* itself." [1]

It may be proved, however, from mechanical principles, that the rings cannot possibly be solid. The hypothesis that they may be liquid is also untenable. The theory now generally adopted by astronomers is that they consist of a swarm of minute satellites which revolve round the planet in separate orbits.

Comparatively speaking the rings are very thin—probably not more than 100 miles in thickness. When the plane of the rings passes through the earth,

[1] *Monthly Notices*, R.A.S., January, 1890.



which occurs at intervals of $14\frac{3}{4}$ years (half the period of revolution), the edge only is visible, and in this position the ring system, being so thin, disappears, even in a telescope of considerable power.

Saturn is probably in a red-hot state, like Jupiter. The light reflecting power of the planet is considerably less than that of Jupiter, but judging from its small density, and the appearance of "belts" on its surface, similar to those of Jupiter, it seems probable that the planet is in a heated condition. *Most* of Saturn's light is, however, merely reflected sunlight.

# CHAPTER XV.

## URANUS AND NEPTUNE.

WE now come to a planet which was unknown to the ancient astronomers. Uranus was discovered by Sir W. Herschel on March 13, 1781, and was at first mistaken for a comet, but its planetary nature was soon determined, and it was found to revolve round the sun in an orbit exterior to that of Saturn.

Its mean distance from the sun is about 1,782 millions of miles, or more than double the distance of Saturn. It takes about 84 years to perform one revolution round the sun.

Uranus is very much larger than the earth, but considerably smaller than Jupiter and Saturn, its diameter being about 33,600 miles. In density, however, Uranus is much lighter than the earth, its specific gravity being about equal to that of water.

Uranus most probably rotates on its axis, like the other planets, but owing to its small disc, and the difficulty of seeing any markings on its surface, even with large telescopes, the period has not been ascertained. Judging, however, from the analogy of Jupiter



and Saturn, it seems probable that the period does not differ much from 10 hours.

There are four known satellites which have been named Ariel, Umbriel, Titania, and Oberon, in order of their distance from the planet. The distances of these moons range from about 125,000 miles to 382,000 miles. Unlike the satellites of the planets already considered, the planes of their orbits are nearly at right angles to the plane of the ecliptic, and the motion is retrograde—that is, they move from east to west, instead of from west to east.

When favourably situated Uranus shines as a star of about $5\frac{1}{2}$ magnitude, and is just visible to the naked eye. It may be seen, however, with an opera-glass on any clear night, if its position is accurately known. At present (Oct., 1890) it is situated a little to the east of the bright star Spica ($\alpha$ Virginis).

From recent observations with the spectroscope, it seems probable that—like Jupiter and Saturn—Uranus is still in a highly heated condition. From its observed brightness I find that its brilliancy is considerably greater than theory would lead us to expect in a planet so far from the sun. Before its discovery as a planet, Uranus was observed no less than 20 times, and recorded as a fixed star on each occasion.

NEPTUNE.—Next to Uranus comes Neptune, the most distant known member of the planetary system. It was discovered on Sept. 23, 1846; but its existence had previously been predicted, and its position pointed

out by two young mathematicians, Adams in England, and Le Verrier in France. After the discovery of Uranus, irregularities were observed in its motion which the theory of gravitation could not account for. The discrepancies between the computed and observed places of Uranus at last became so considerable that astronomers were led to suspect the existence of an unknown planet outside Uranus, which, by its attraction, was disturbing the motion of Herschel's planet. The enormously difficult mathematical problem of calculating the position of this hypothetical planet was independently undertaken by the two mathematicians I have just named. The result was the telescopic discovery of the planet by Galle at Berlin close to the computed position. This was a splendid scientific triumph, and in the opinion of some astronomers the discovery of Neptune forms the most brilliant achievement in astronomy since the discovery of the law of gravitation by Sir Isaac Newton.

The mean distance of Neptune is about 2,792 millions of miles, or about 30 times the earth's distance from the sun. The period of revolution is about 164½ years, or nearly double that of Uranus.

Neptune is somewhat larger than Uranus, its diameter being nearly 38,000 miles. In density, however, it is rather lighter, being about 0·9 (water equal 1). The period of revolution on its axis is unknown.

Only one satellite of Neptune has, up to the present,


FIG. 19.—POSITION OF NEPTUNE OBSERVED BY LALANDE MAY 8TH AND 10TH, 1795.

been discovered. Like the Uranian satellites its motion is retrograde, and the plane of its orbit is inclined to the plane of the planet's orbit at a considerable angle. It revolves round Neptune in 5 days, 21 hours, at a distance of about 220,000 miles, or somewhat less than that of our moon. The fact of its being visible at all at the great distance which separates us from Neptune makes it probable that it is a body of considerable size.

As in the case of Uranus, Neptune was—previous to its discovery as a planet—observed and recorded on several occasions as a fixed star. The accompanying diagram (fig. 19) shows its position as observed by Lalande on May 10, 1795.

## CHAPTER XVI.

### COMETS.

THE student will now like to hear something about the comets. Some of them form members of the Solar System, but the very bright and large ones are, as a rule, only seen once, and must be considered as merely occasional visitors to our system.

The comets which belong to the Solar System travel in elliptic orbits; but these ellipses are generally very elongated—that is, one of the axes of the ellipse—the *major axis*, as it is called—is very much longer than the other, or, as a mathematician would express it, the eccentricity of the ellipse is very great. Other comets, however, are supposed to travel in a curve called the parabola—that is, a curve which does not return into itself, but has two similar branches which run out to infinity. In this case a comet having once passed round the sun would go off into space never to return. As, however, it is difficult to determine whether the small portion of the orbit near the sun belongs to an ellipse or parabola—both curves nearly coinciding near the focus—it is not always certain whether a

comet is really travelling in a parabolic orbit. The orbit may, in many cases, be really an ellipse of great length.

Among the comets known to be regular *members* of the Solar System, there are two groups, one consisting of small comets with periods ranging from $3\frac{1}{3}$ years (Encke's) to $13\frac{3}{4}$ years (Tuttle's). These can only be observed with a telescope. The second group consists of 5 comets having periods of $67\frac{3}{4}$ to $76\frac{3}{4}$ years. The most remarkable of these is that known as Halley's, which has a period of about 76 years. Apparitions of this comet have been traced back to B.C. 11. Its last appearance took place in 1835, and its next return is due in the year 1910.

The periods of some of the large comets have also been calculated, but the great length of the computed periods renders them very uncertain. The famous comet of 1811 was calculated by Argelander to have a period of over 3,000 years! The magnificent comet of 1858, known as Donati's, has been computed to have a period of about 2,000 years. The great comet of 1861 seems to have been moving in an elliptic orbit, with a period of about 419 years. Coggia's comet of 1874 is supposed to have a period of over 10,000 years! That of 1882 was well observed, and its period has been fixed at 772 years, with considerable approach to accuracy.

Comets have been for ages a mystery to astronomers; but it is now thought possible that the *head* may consist of a cloud of meteoric stones, and that



the *tail* is due to electrical repulsion existing in the sun which drives out into space the minuter particles of matter contained in the nucleus. This theory explains the observed fact that the tail is gradually formed as the comet approaches the sun, and afterwards disappears as the comet recedes into space.

Some comets approach the sun very closely; the great comets of 1680, 1843, and 1882 nearly grazed the surface of the sun. Those of 1843 and 1882 were seen with the naked eye close to the sun in broad daylight.

## CHAPTER XVII.

### DOUBLE AND BINARY STARS.

A DOUBLE star is one which appears to the naked eye as an ordinary single star, but when examined with a good telescope is seen to be composed of two stars very close together.

The number of these interesting objects now known to astronomers probably exceed 10,000. These, however, include objects of varying character; some being easily seen with small telescopes, while others cannot be clearly separated by the highest powers of the largest telescopes yet constructed!

There are some stars which may be seen double with the naked eye or an opera-glass, but these cannot properly be termed "double" stars, at least astronomers would not consider them so. Some observers speak of those visible to the unassisted vision as "naked eye doubles," but this is of course only a popular way of speaking. You may have noticed a small star close to the centre star in the tail



of the Great Bear (or handle of the "Plough"). This is called by some "Jack on the Middle Horse," and, though now clearly visible to good eyesight, it was called by the ancient astronomers Alcor, or the "test," as it was then considered rather a difficult object, and a test of keen vision. It may possibly have increased in brightness, but the evidence in favour of variation in its light at present does not seem to me conclusive.

Only a few stars are, however, close enough to look—to the naked eye—like real double stars, but I may mention the brightest star in the constellation Capricornus, which can be easily seen double with good eyesight on a clear night. The star known as $o$ Cygni (a little to the west of $\alpha$ Cygni) is another example. The most southern of the stars in the "sword" of Orion, $\iota$, may also be seen double on fine nights, but this is perhaps a more difficult object than the others. The most severe test, however, visible in these latitudes is the star $\epsilon$ Lyræ (near Vega), which some eyes can see double. It is, however, easily visible in a good opera-glass. This is a very remarkable star, as with a good telescope each of the components is seen to be again double, forming a "double-double" or quadruple star, and between the pairs are several fainter stars.

In many cases—especially in the wide pairs—the components are, in all probability, only apparently close together, and when one of the stars is very much fainter than the other it possibly lies at a vast distance

behind the brighter star.[1] There are many cases, however, in which the components are really close together, and therefore at nearly the same distance from the earth. In these double stars Sir William Herschel discovered that one of the components actually revolves round the other, in the same way that the earth and other planets revolve round the sun, and these are called Binary, or revolving double stars.

These are most interesting objects—revolving suns. Their periods of revolution vary from about 11 years to over 1,000 years. The shorter periods are, however, comparable with those of the larger planets, Jupiter, Saturn, Uranus, and Neptune.

I said that the orbits of the earth and the larger planets were ellipses, but nearly approaching the circular form. In the majority of the binary stars the orbit is a lengthened ellipse ; some of them, indeed, resembling more the orbits of comets than planets. In others, however, the orbit does not differ more from a circle than that of Mercury, and in a few instances the orbit approaches even still closer to the circular form.

A considerable number of stars are known to be binary, and others are suspected, but the orbits of

[1] There are, however, notable exceptions to this rule ; for instance, Sirius, δ Cygni, 85 Pegasi, 99 Herculis, all of which form binary systems. I have quite recently computed an orbit for 99 Herculis and find a period of 53½ years, with an ellipse of large eccentricity.



only about 60 have been hitherto calculated by astronomers. Some of these are bright stars ; others faint. The following are bright stars :— Sirius, α Centauri, Castor, γ Leonis, γ Virginis, ζ Sagittarii, ζ Herculis, β Delphini, δ Cygni, η Cassiopeiæ, and others.

The periods being so long these binary stars require to be watched for many years before any apparent change becomes visible. In some cases we have observations of the more remarkable, extending more than 100 years back.

In watching the motion of these revolving stars we do not see the real orbit described. From the principles of mechanics the student will understand that the component stars really revolve round their common centre of gravity, which lies somewhere between them. But, for convenience of measurement and calculation, one of the stars—the brighter of the two —is supposed to be at rest, and the whole of the observed motion to take place in the other. The orbit thus observed is called the *apparent* orbit, and even this does not represent the real motion, for as a rule the plane in which the components revolve is *inclined* to the line of sight, and only in the case where this plane happens to be at right angles to the line of sight—a rare case—do we ever see the *real* orbit of a binary star.

The *apparent* orbit observed differs considerably in shape from the real orbit. But both orbits are ellipses, or rather are assumed to be so, on the supposition

that the law of gravitation holds good in these systems as well as in our own Solar System, which is of course highly probable. According to Kepler's second law, equal areas are described in equal times. This is true for *both* the *apparent* and the *real* ellipse. In fact the law is true for a body moving in *any* curve round a centre of force.

The reader might like to see the apparent orbit of one of these binary stars. Here is a diagram (see fig. 20) of the apparent orbit of the companion of Sirius which I have myself recently computed.[1] It shows the form and position of the apparent ellipse, and the portion of the orbit which has been described by the small star since its discovery in 1862. Sirius is the brightest star in the heavens. It has a considerable "proper motion," and from irregularities in this motion, which could not otherwise be explained, astronomers came to the conclusion that its motion was disturbed by the attraction of some unknown companion. Shortly after this opinion was published a faint companion was discovered by the celebrated optician, Alvan Clark, in America; and careful observations since that time fully confirm the suspicion that it is actually revolving in an orbit round Sirius. In the diagram, C is the centre of the apparent ellipse, A the position of the bright star. The dates show the position of the faint star in the years given. If C and A be joined, and produced both ways, this line will represent the projection of the *major*, or longer

[1] *Monthly Notices*, Royal Astronomical Society, June, 1889.

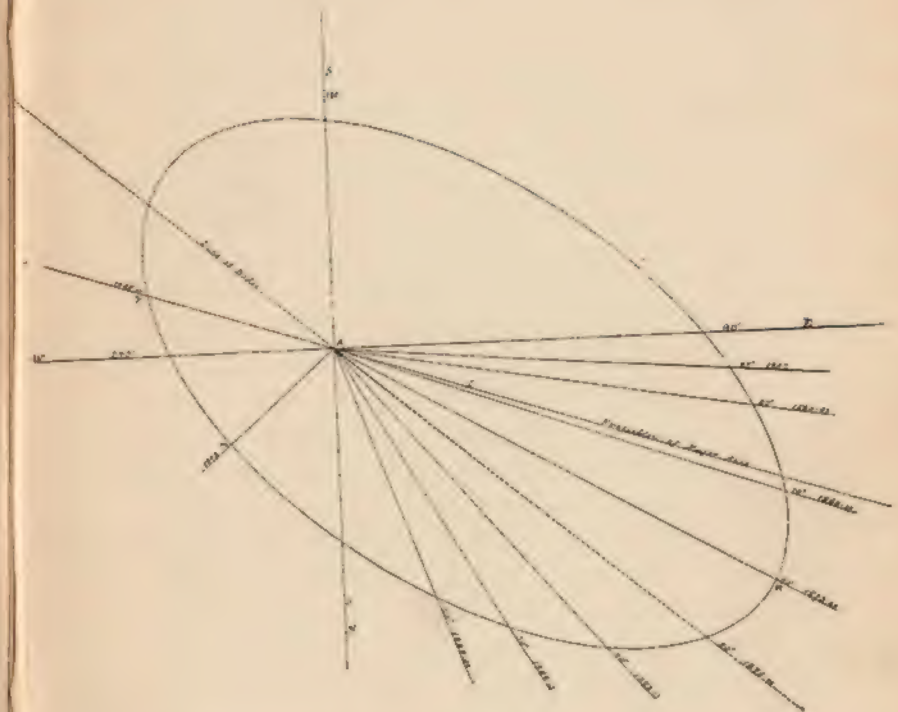


FIG. 20.—APPARENT ORBIT OF THE COMPANION TO SIRIUS AS COMPUTED BY J. E. GORE.

axis, of the *real* ellipse, and P is the *periastron*, or point of nearest approach in the *real* orbit. It will be seen that the point marked *m* is the point of nearest approach of the components in the *apparent* orbit (M that of greatest distance), and does not coincide with the periastron point in the real orbit.[1]

When the real orbit is at right angles to the line of sight, the minimum distance is then at the periastron, and in one or two other cases; but as a general rule the point of nearest approach is *not* at the *periastron*.

The line marked in the diagram "line of nodes" is the line of intersection of the plane of the *real* orbit with the plane on which the orbit is projected, or the background of the sky (or the plane of the paper in the diagram). One half the orbit is *below* this plane, the other half *above* it; but it is impossible to decide from the observations of position which half is below and which above.

The orbits formerly computed for Sirius gave a period of 49 or 50 years, but I find that recent measures require a somewhat longer period—about 58½ years.

There are many other interesting binary stars. One of the most remarkable is γ Virginis, which has a period of about 185 years. During last century it

[1] The mistaken idea that the least distance *always* occurs at the *periastron* seems a not uncommon one. Some years since a well-known astronomer expressed his opinion that the famous binary star α Centauri had not then reached the periastron, *because* the components had not yet reached their minimum distance!



was an easy object, even in small telescopes, but it gradually "closed up," and in the year 1836 became so close that the most powerful telescopes of that day could not show it as anything but a single star! It then "opened out" again, and is at present an easy object, even with a small telescope. The ellipse in this case is very elongated, very much indeed resembling the orbit of a comet. Another elongated orbit is that of the southern star α Centauri—the nearest "fixed star" to the earth—as far as has yet been determined. The period is about 77 years. Another interesting binary is 70 Ophinchi, for which I have also computed an orbit, and find a period of about 88 years.[1] The German astronomer, Schur, some years since found a period of about 94 years, but this does not satisfy recent observations. The bright star Castor also consists of two components, of which the period is about 1,000 years.

The shortest period known is δ Equuleii, for which the Russian computer, Wrublewsky, finds a period of about 11½ years. It is a very close pair, and can only be measured with the largest telescopes. Other binary stars with short periods are ζ Sagittarii, β Delphini, 85 Pegasi, and 42 Comæ.

The calculation of these double star orbits is generally difficult and troublesome. The measures of the same star by different astronomers often differ so considerably that it requires much experience and patience to obtain anything like a satisfactory result.

[1] *Monthly Notices*, R.A.S., March, 1888.

In most cases also the portion of the ellipse hitherto described is so small that the exact ellipse, of which it forms a segment, must be uncertain.

There are some cases, however, in which a complete revolution has been performed. The star known as ξ Ursæ Majoris has completed a full revolution since its discovery by Sir W. Herschel in 1780. In 42 Comæ more than two complete revolutions have been performed; the period is about 25¾ years. The components of ζ Herculis have revolved nearly three times since 1782—period about 34 years. The orbits of these stars have consequently been ascertained with considerable accuracy.

## CHAPTER XVIII.

### VARIABLE STARS.

THE variable stars are those which are not constant in their light, but which vary in brightness. Some of them vary to a very great extent, but others only slightly. They form a very interesting and mysterious class of objects.

Over 200 stars are known to be certainly variable, and many others have been suspected.

Some of these variables may be observed with the naked eye. Perhaps the most remarkable of them all is that known as Mira, or the "wonderful" star, in Cetus. This extraordinary object has a period, from maximum to maximum, of about 331 days. When at its brightest it shines as a star of about the 2nd magnitude.[1] At the minima it diminishes to about the 9th magnitude.[2] The exact position of the star will be seen from the following

[1] Sometimes, however, it does not rise above the 4th magnitude.

[2] It always remains visible in a telescope of 3 inches aperture.

diagram (fig. 21), which will enable the student to find it in the sky without much difficulty.

Another remarkable object of this class is the star known as Algol, or $\beta$ Persei. The fluctuations in the light of this star are very curious. The period is very short—about 2 days, 20 hours, 48 minutes, 51 seconds. For the greater portion of this period the light of the star remains steady at a little below the 2nd magnitude. It then begins to diminish in brightness, and in about 4 hours, 23 minutes is reduced to a star of about magnitude $3\frac{3}{4}$. At this brightness it remains for about 15 minutes, when the light again begins to increase, and in about $5\frac{1}{4}$ hours it recovers its ordinary brilliancy. The accompanying diagram (fig. 22) will enable the student to easily find this curious star. As, however, the minima of light occur at all hours of the day and night, it is not an easy matter to "catch" it at its faintest. From the end of March to the beginning of August the star is not favourably situated for observation, being low down on the northern horizon during the early portion of the night. The epochs of minimum are given in Whittaker's Almanac.

The "Algol stars" form a very rare type of variable, only 9 having hitherto been detected. Most of these are small, and not easily observed, but the following are visible to the naked eye: $\lambda$ Tauri and $\delta$ Libræ. There is another interesting class of variables known as "short period" variables. These are in a constant state of variation in periods ranging

FIG. 21.—THE VICINITY OF MIRA (o) CETI.

from 1 day to 17 days. Of these the following are tolerably bright stars: ζ Geminorum, period about 10 days, 3¾ hours; β Lyræ, period about 12·9 days; η Aquilæ, period 7 days, 4 hours, 14 minutes; and δ Cephei, period 5 days, 8 hours, 47 minutes, 40 seconds.[1] Other smaller objects of this class are known, some of them very interesting, but the aid of an opera-glass is required to follow their fluctuations.

No very satisfactory theory has yet been advanced to account for the changes of brightness in stars of long period, but in the case of stars of the Algol type it is thought probable that the diminution of light is due to the interposition of a dark eclipsing satellite which, at the star's minimum, cuts off a portion of its light, and some recent spectroscopic observations by Vogel seem to show that this is really the solution of the mystery.

[1] Further particulars respecting these and other variable stars will be found in my "Scenery of the Heavens."


FIG. 22.—THE VICINITY OF ALGOL (β PERSEI).

# CHAPTER XIX

## THE NEBULÆ.

In addition to the thousands of stars visible in the heavens, there are a large number of objects known as *nebulæ*, from their hazy appearance. Over 8,000 are now known to astronomers, and doubtless there are many more.

A few of the nebulæ are visible to the naked eye; for instance, the great nebulæ in Andromeda and Orion; but the great majority are only visible with a good telescope.

Many of them, although usually classed under the general head of *nebulæ*, are really clusters of small stars; others, or the true nebulæ, are known—from observations of their light with the spectroscope—to consist of nothing but glowing gas, or mixture of gases, of which hydrogen is certainly one constituent.

The great nebula in the "Sword" of Orion is a mass of luminous gas. It may be well seen with a small telescope, but of course large instruments are necessary to show the details of this wonderful object. It has been recently photographed with great success.



No telescope has yet succeeded in resolving the great nebula in Andromedæ into stars, but the spectroscope shows that it is *not* gaseous. Probably it consists of very small stars, or possibly a swarm of meteorites so small as to be individually invisible at the immense distance which separates it from the earth. A wonderful photograph of this object recently taken by Mr. Roberts at Liverpool shows a number of rings partially separated from the central mass.

Several of the clusters may be seen with a small telescope. One in the constellation Gemini, a little north of the star $\eta$ in that constellation, may be well seen with a 3-inch telescope, although, of course, larger instruments are necessary to show the fainter stars. The cluster known as 34 Messier, between $\beta$ Persei (Algol) and 60 Andromedæ, is a very good object for a small telescope. I have seen stars sparkling in this cluster with a binocular field-glass. The double cluster near $\chi$ Persei is another splendid object in a small instrument. This has been recently photographed at the Paris Observatory. Among the globular clusters, one between $\eta$ and $\zeta$ Herculis is a magnificent object in a good telescope. This has also been photographed. Further particulars respecting the nebulæ and clusters, and photographs of some of them, will be found in my "Scenery of the Heavens."

# INDEX.

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ASTRONOMICAL LESSONS - GORE.